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SLOTS IN THREE CENTIMETER
RECTANGULAR WAVE GUIDES

BY

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An investigation carried out under the direction of Professor J.W. Porteous.

Presented to the Committee on Graduate Studies, the University of Alberta, as a partial requirement for the degree of Master of Science.

UNIVERSITY OF ALBERTA

DEPARTMENT OF ELECTRICAL ENGINEERING

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CONTENTS

Page

Preface 1

Introduction 2

Impedance of Slots 8

Standing Waves and Impedances in Wave Guides 11

Slot Radiation and Measurement of Gain 13

Description of the Apparatus 15

Experimental Technique 19

Thesis Data and Discussion 23

Experimental Slot Radiation 42

Accuracy of Results 48

Nomenclature 49

Bibliography 50

Equipment Circuit Diagram 51

PREFACE

This thesis deals with research carried out on slots cut in the broad side wall of three centimeter rectangular wave guide.

The effective impedance for slots of various lengths, widths and angles of orientation relative to the guide axis was investigated. From the data obtained a resonant half wave slot was designed and its impedance, determined. The Smith Circular Transmission Line Impedance Chart was used to determine the resistance and reactance components of the slot impedance.

Radiation patterns for the various slots were obtained, and are included in this paper.

The author wishes to thank Professor J.W. Porteous under whose guidance this investigation was carried out.

INTRODUCTION

Electromagnetic wave propagation has, in recent years, been the subject of extensive research and practical application. Electromagnetic waves may be classified, generally speaking, as waves in free space, or as guided waves. Waves in free space are exemplified by the radiation between transmitting and receiving antennae found in radio communication. Examples of guided waves are to be found in power transmission, radio frequency co-ax ial line transmission and wave guide transmission.

The mathematical analysis of electromagnetic wave propagation consists of the solution of the general wave equation. The fundamental field equations [1] from which the general electromagnetic wave equation is derived are obtained from the works of Gauss, Ampere, Faraday, Ohm and Maxwell.

For guided waves, due to boundary conditions and initial conditions, certain terms in the general solution of the equation become zero. The electromagnetic field is determined by specifying the fields laid down at the source

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[1] Sarbacher and Edson - Hyper and Ultra High Frequency Engineering, Chapter I.
Skilling - Fundamentals of Electric Waves.
Ramo and Whinnery - Fields and Waves in Modern Radio.

of excitation, the shape and dimensions of the conductor and the properties of the medium.

The source of excitation may be made to produce various field configurations which will or will not propagate depending on the shape and dimensions of the conductors. These field configurations are called modes.

The specific case is now considered. The wave guide is aligned as in Fig. 1, in the rectangle coordinate system so that the direction of propagation will be along the "z" axis. The source of excitation is such that the electric field E will be parallel with the "x" axis. The resultant mode of transmission will be what is called the Transverse Electric, or T.E. wave.

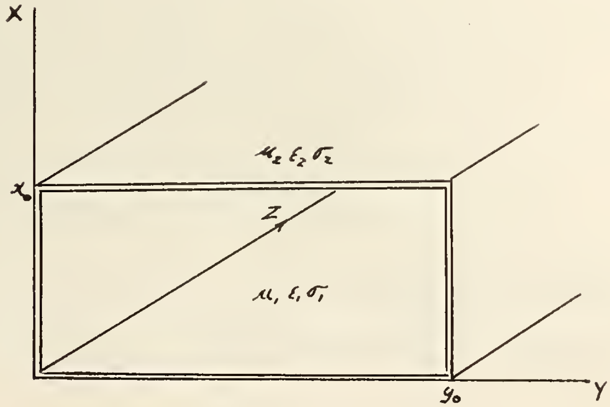

Fig. 1. Guide Orientation.

The behavior of propagation is assumed to be described by the function $e^{jwt-\gamma z}$ where the function represents a wave travelling in the "z" direction, having a frequency $f = \frac{w}{2\pi}$ and a propagation constant $\gamma = \alpha + j\ddot{B}$; where α is the attenuation constant and $\ddot{B}$ is the phase constant of the system. Considering the boundary conditions, E_y must be zero at $x = 0$, $x = x_0$; $E_x = 0$ at $y = 0$, $y = y_0$. For a dielectric of very low conductance the propagation constant is found to be given by [2]

$$\gamma_{mn} = \sqrt{\frac{(n\pi)^2}{(x_0)^2} + \frac{(m\pi)^2}{(y_0)^2} - w^2\mu_1 \epsilon_1}$$

The factors "m" and "n" indicate the number of half sinusoids of field distribution possible between $0 < y < y_0$ and $0 < x < x_0$. These factors determine the mode of the transmitted wave. For a given frequency the dimensions of the guide will determine the possible modes which will propagate if excited. As the frequency decreases the wave length increases causing "m" and "n" for a certain guide to decrease thus cutting out the higher modes of transmission. The wave guide will act as a high pass filter.

The wave guide used in the investigation was of dimensions such that y_0 was greater than a half wave

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[2] Sarbacher and Edson, Chapter 6.

length, x less than a half wave length; hence $m = 1$, $n = 0$. The propagating wave, a TE_{10} wave, has the following field equations.[3]

$$E_y = 0$$

$$E_x = A \frac{\pi}{y_o} \frac{j\omega\mu_1}{\gamma_{10} + \omega^2 \mu_1 \varepsilon_1} \sin\left\{\frac{\pi}{y_o} y\right\} e^{j\omega t - z\gamma_{10}}$$

$$E_z = 0$$

$$H_y = A \frac{\pi}{y_o} \frac{\gamma_{10}}{\gamma_{10} + \omega^2 \mu_1 \varepsilon_1} \sin\left\{\frac{\pi}{y_o} y\right\} e^{j\omega t - z\gamma_{10}}$$

$$H_x = 0$$

$$H_z = A \cos\left\{\frac{\pi}{y_o} y\right\} e^{j\omega t - z\gamma_{10}}$$

The propagation constant $\gamma_{10} = \alpha + jB$ reduces to

$$\gamma_{10}^2 = \left\{\frac{\pi}{y_o}\right\}^2 - \omega^2 \mu_1 \varepsilon_1$$

The critical frequency, that frequency at which the β of the propagation constant is zero, will be

$$f_c = \frac{1}{2\pi\sqrt{\mu_1 \varepsilon_1}} \quad \frac{\pi}{y_o} = \frac{v_1}{2y_o}$$

Where v_1 is the wave velocity in the dielectric

The critical wave length

$$\lambda_{c_{10}} = 2y_o$$

The phase constant β where $\alpha = 0$ is given by

$$\beta_{10} = \sqrt{\omega^2 \mu_1 \varepsilon_1 - \left\{\frac{\pi}{y_o}\right\}^2}$$

The wave length in the guide becomes

$$\lambda_g = \frac{2\pi}{B_{10}} = \frac{\lambda_1}{\sqrt{1 - \left(\frac{\lambda_1}{\lambda_c}\right)^2}}$$

where λ_1 is the wave length in the dielectric when unbounded, and λ_c is the critical, or cut off, wave length.

The field equations are represented graphically in Fig. 2. The wave guide field distribution[4], shown in Fig. 3 indicates the relationship between $\bar{E}$, $\bar{H}$, $\frac{\partial \bar{D}}{\partial t}$ $\bar{i}_c$ charge density ρ and Poynting's flux $\bar{S}$, as found in the T.E.$_{10}$ wave. This distribution of fields will be used to explain the impedance effect of slots.

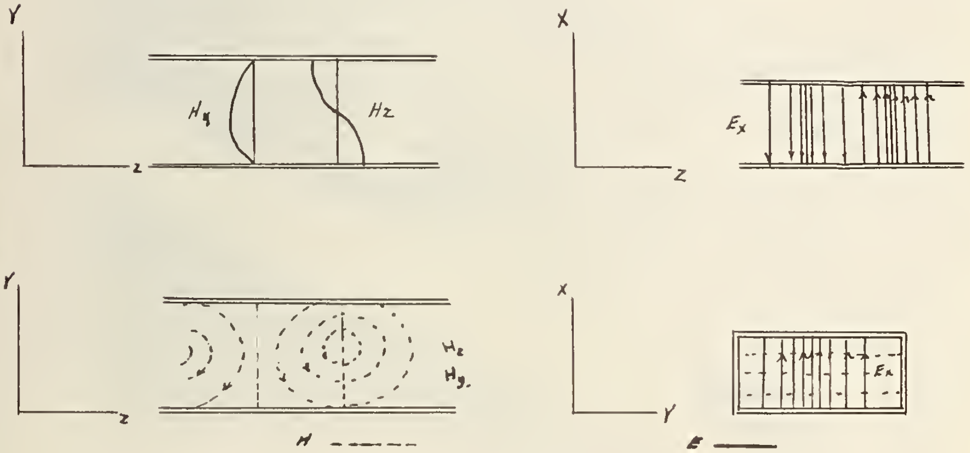

Fig. 2
Instanteous T.E.$_{10}$ Field Configuration in the Dielectric of a Rectangular Wave Guide.

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[3] Sarbacher and Edson.

[4]. Electronics, February, 1945.

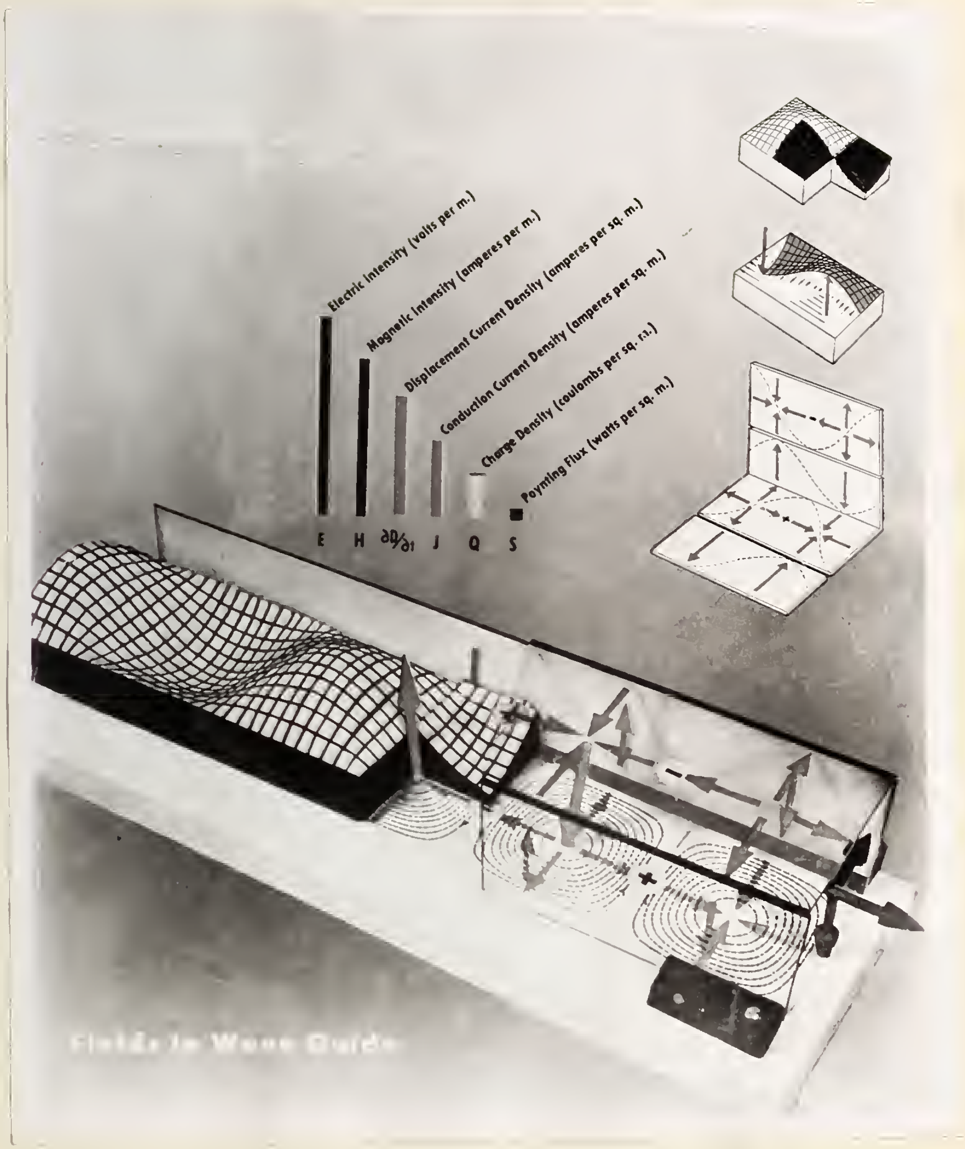
Electric Intensity (volts per m.)
Magnetic Intensity (amperes per m.)
Displacement Current Density (amperes per sq. m.)
Conduction Current Density (amperes per sq. m.)
Charge Density (coulombs per sq. m.)
Poynting Flux (watts per sq. m.)
E
H
∂D/∂t
J
Q
S
+
Fields in Wave Guide

Fig. 3 T.E.$_{10}$ Fields in Rectangular Wave Guides

Impedance of Slots

The foregoing mathematical relationships describe the field configurations in the guide. Attention will now be directed to a consideration of the impedance effect due to the presence of a slot opening in the guide wall.

A small opening in the wide side of a rectangular wave guide bearing a T.E. 10 wave is shown in Fig. 4. The electric field outside the guide may be considered to be a superposition of the electric field due to the guide electric field fringing at the opening, and an electric field due to the effect of the magnetic field in the guide. The guide magnetic field causes a flow of charges along the guide. The opening will interrupt the normal flow of charges, thus establishing an electric field due to the difference in potential produced across it.

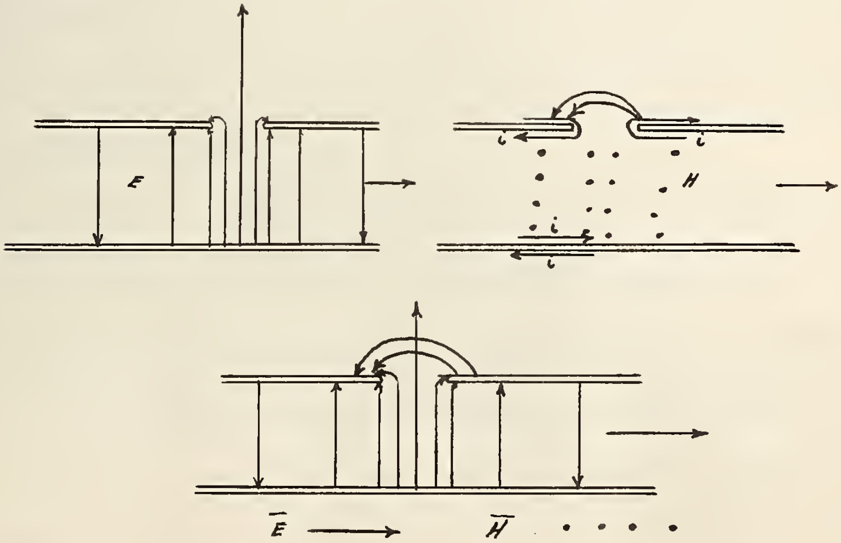

Fig. 4. Electric Field Outside an Opening in the Wide Side of a Rectangular Wave Guide.

A slot impedance, generally speaking, is a combination of shunt and series reactances. This is due to the fact that the slot is excited by both the electric field normal to the slot, and the magnetic field parallel to it. The slot would be equivalent to a shunt reactance if only the electric field normal to it was present, or a series reactance for only the magnetic field present.

The field distribution in Fig. 3 shows that the maximum electric field intensity and maximum flow of charges, due to the magnetic field, are separated by a quarter of a wave length. If the center of the slot is a quarter wave length from a guide terminating short, the electric field Ex will be a maximum at the slot and the shunt effect of the slot may be considered. If the wave guide is terminated in a short, a half wave length from the slot, the transverse magnetic component Hy of the field is effective and the series effect of the slot may be noted.

The effective impedance of a slot may be considered in terms of current flow in the guide wall. If the slot is excited only by the longitudinal current component, due to the magnetic field distribution as shown in Fig. 4 (b) the slot acts as a series load. If the slot is excited by a transverse current due to electric field distribution it acts as a shunt load.

A narrow slot cut in the broad wall of the guide with its longitudinal axis parallel to the guide axis behaves as a shunt load. If the slot length is about $\frac{\lambda}{2}$ a pure conductance is found, given by the equation[5].

$$G = K \sin^2 \frac{\pi y_1}{a}$$

where "a" is the guide width, K is a constant depending on the slot dimensions and the wave length, and y_1 is the slot displacement from the center line of the guide.

Slots cut so that their centers are on the guide centerline, should have a zero shunt admittance. Therefore only series load effects should be indicated by them.

The maximum series impedance of a slot, when rotated about its center, located on the guide centerline, will be found when it presents a maximum length perpendicular to the longitudinal surface current flow. This will be when the slot is at an angle of 90° to the guide axis.

A resonant slot is a slot having a length of about $\frac{\lambda_1}{2}$ giving rise to a pure resistive load effect.

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5. Watson, W.H. - Resonant Slots, Journal of the Institute of Electrical Engineers, Vol: 93:

Standing Waves and Impedances in Wave Guides.

In transmission line theory, the line is said to be matched if the load impedance terminating the line is equal to the characteristic impedance of the line. Under these conditions the line acts as an infinite line, having no reflected wave.

The wave guide is, in its simplest form, a transmission line, the wires of which are separated by short circuited quarter wave length stubs giving rise to the effect of infinite impedance. Transmission line theory may be applied to the wave guide . If the guide termination impedance is not equal to the guide characteristic impedance the reflected wave will combine with the oncoming wave to produce a standing wave.

The characteristic impedance of the wave guide is defined[6] as the ratio of the magnitudes of the transverse electric field to the transverse magnetic field for a given mode. For the T.E. 10 wave the impedance will be.

$$Z_0 = \frac{E_x}{H_y} = \sqrt{\frac{\mu_1}{\epsilon_1}}\ 377\ \frac{\lambda_g}{\lambda_1}$$

Consider the wave encountering a reflecting surface or

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[6] Ramo and Whinnery - Fields and Waves in Modern Radio Page, 252.

discontinuity as in Fig. 5. If A is the amplitude of the outgoing wave, A_1 the amplitude of the reflected wave and A_2 the amplitude of the resultant continuing wave, it may be shown that the standing wave ratio will be given by S.W.R. = $\frac{A + A_1}{A - A_1}$

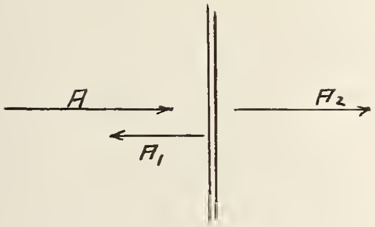

Fig. 5. Wave Reflection

From transmission line theory the standing wave ratio is the ratio of the load impedance to the line characteristic impedance. Similarly in wave guides.

$$\mathrm{SWR} = \frac{Z_L}{Z_o}$$

In experimental work for determining the effective load on the guide it is necessary only to know the standing wave ratio due to the mismatch, the guide characteristic impedance Z_o and the phase shift of the standing wave due to the reactive component of the load.

By means of the Smith Circular Transmission Line Impedance Chart both the resistive and reactive components of the load may be obtained.

Slot Radiation and Measurement of Gain

The directional properties of radiation from an excited slot may be specified by the term gain. Gain is usually defined as the ratio of the intensity of radiation in the direction of maximum intensity, to the radiation intensity that would be found if radiation were equal in all directions. Relative gain is often given in terms of radiation relative to that found for some secondary standard such as a dipole.

Gain may be measured by Purcell's Reflecting Plate Method[7] for matched horns. The slot is used in place of the horn. The equation for gain is given as follows, with reference to Fig. 6.

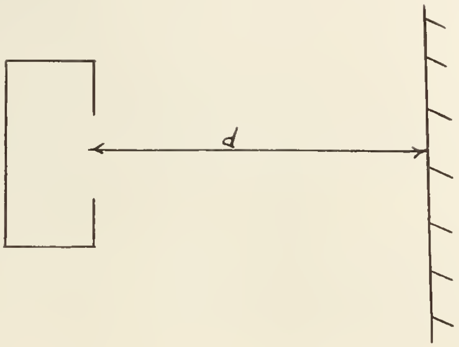

Fig. 6. Purcell's Reflecting Plate Arrangement.

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[7] Pon, Richard H. - The Absolute Gain Measurement of Electro Magnetic Horns. M. Sc. Thesis. University of Alberta.

$$G = \frac{8\pi d,}{\lambda} Rc$$

where d is - the distance between the slot and the plate, and R_c is the reflection coefficient of the load on the face of the slot.

$$\text{i.e.} \quad R_c = \frac{SWR - 1}{SWR + 1}$$

$$\text{where} \quad SWR = \frac{E\ max}{E\ min}$$

The values of E_{max} and E_{min} are obtained from the standing wave produced in the guide with the reflecting plate placed perpendicular to the slot opening. The distance d has a critical lower value given by the relationship[8]

$$d = \frac{2A^2}{\lambda}$$

where A is the area of the slot and λ is the wave length in air. The area of the slot is very small, hence the critical distance will also be small; less than one centimeter.

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[8] Krutter's Radiation Laboratory Report T - 18

Description of the Research Apparatus

The apparatus used in the investigation consisted of the following units:

(1) A Reflex Klystron three centimeter electro-magnetic wave generator with the power supply and modulator.

(2) An attenuator

(3) A frequency meter

(4) A standing wave detector, 400 cycle amplifier and voltmeter

(5) A matching unit

(6) A guide terminating load

(7) A short circuiting guide termination unit

(8) A large reflecting plate

(9) A turntable

(10) Sections of wave guide, bearing slots of various dimensions.

The apparatus was arranged as shown in Figs. 7 and 7A. The Reflex Klystron tube generated the required signal which, when fed by means of a small antenna into the wave guide, produced the T.E.$_{10}$ wave. The attenuator when lowered into the guide, parallel to the electric field acted as an absorber, thus limiting the amount of power to the load

The frequency meter was essentially a coaxial line

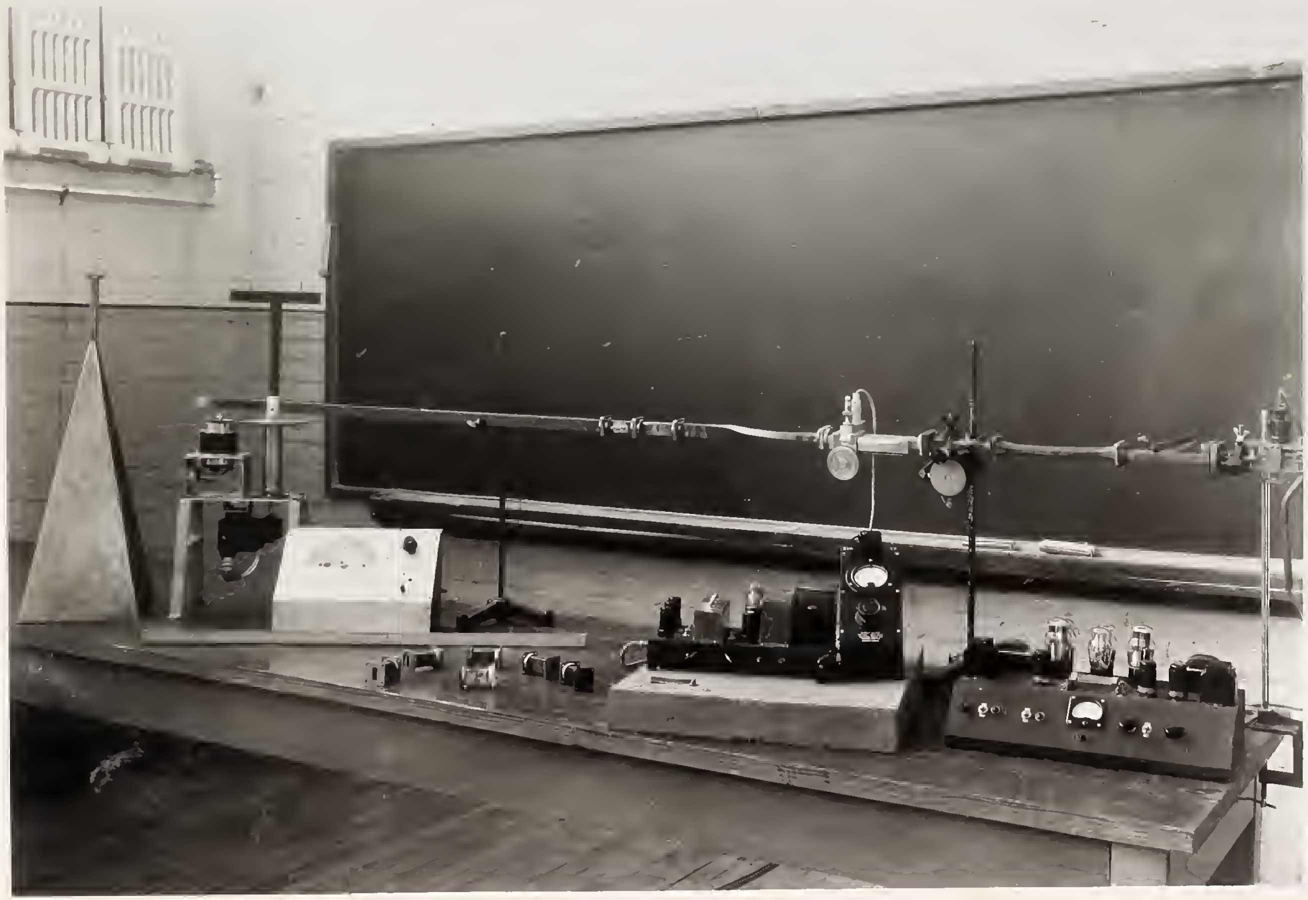
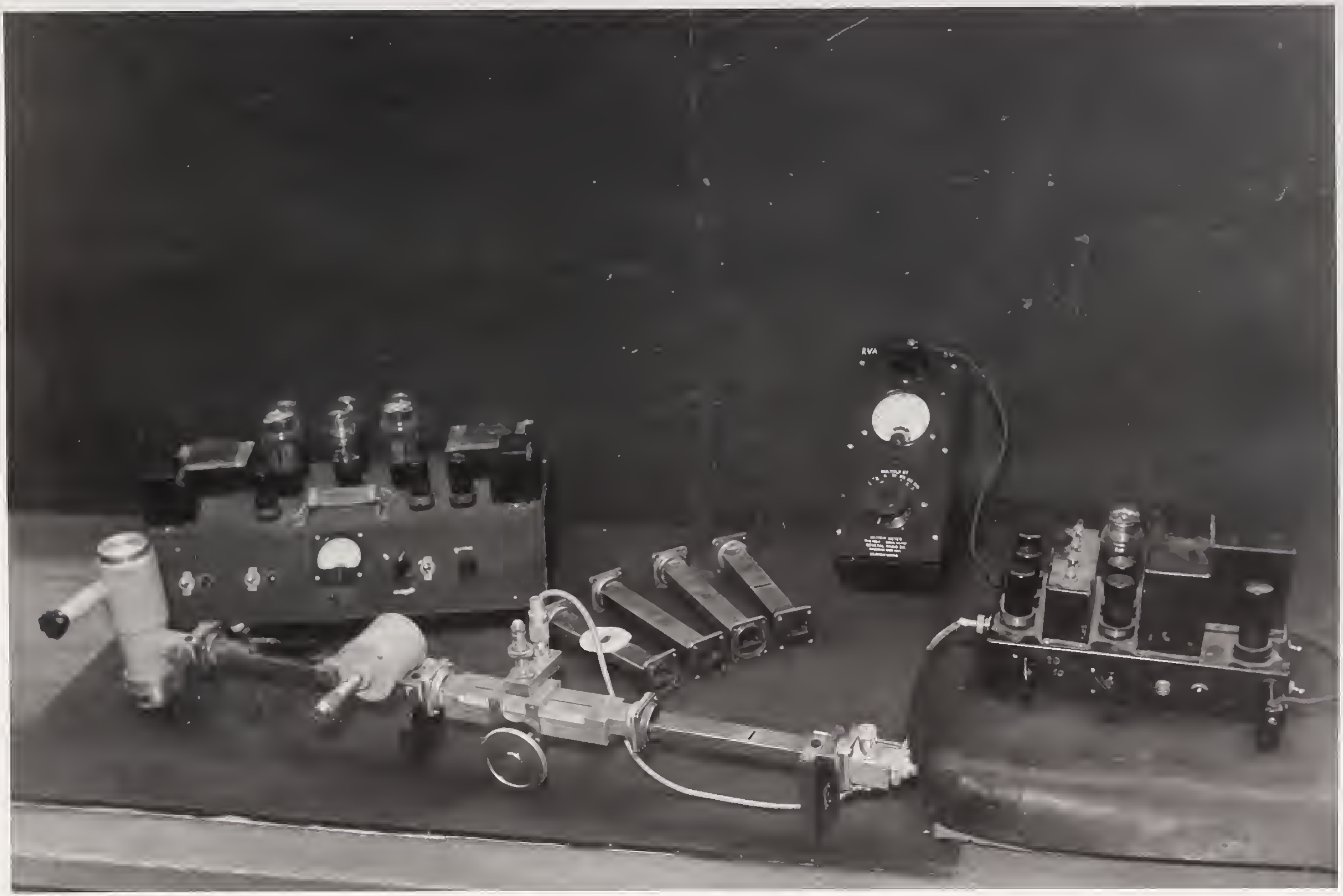


Fig. 7

Experimental Wave Guide Apparatus



section of variable length, which, when tuned to resonance absorbed power - causing the power at the load to decrease greatly. The variation in length used for tuning the meter to resonance was calibrated to read frequency.

The standing wave detector contained a small adjustable probe which could be lowered into the guide, parallel to the electric field, through a long narrow slot cut along the guide centerline. The detected signal was rectified by a crystal, fed into an amplifier tuned to the modulation frequency of the power supply, and thence to the output voltmeter. The crystal detector obeys the square-law relationship.

Standing waves due to mismatch caused by imperfect couplers etc., were greatly reduced by means of a matching unit consisting of two tuning screws set $3/8 \lambda_g$ apart in the wide side of the guide and extending into the guide parallel to the electric field. By adjusting the screws a reflection equal to but of opposite phase to the mismatch reflection was obtained, thus reducing the standing wave found in the guide without a slot, to a minimum.

A guide terminating load having an effective impedance approximately equal to the guide characteristic impedance was constructed. Wood strongly absorbs electro magnetic waves having wave lengths of the order used in the

experimental work. The load consisted of a wooden wedge which fitted snugly in the guide, the sloping surface extending across the wide dimension of the guide. It was found that when the sloping surface was greater in length than 2λg the standing wave ratio due to reflection was less than 1.05. Using the matching unit it was possible to reduce this standing wave ratio.

The short circuiting guide termination unit consisted essentially of a metal plunger placed across the guide. Contact with the side wall was assured by means of a metallic spring seal which acted parallel to the electric field thus establishing a position of zero electric field.

The position of the zero electric field could be varied by means of a screw adjustment which altered the location of the plunger assembly.

Radiation patterns were obtained with the slots operated as receiving antennae. By means of the turntable the slots were rotated in a constant field. The turntable rotation was conveniently observed by means of a selsyn motor arrangement.

The large reflecting plate was a glass plate bearing two coats of silver plating which acted as a reflecting surface. The plate was mounted on a slide enabling it to be moved back and forth when investigating gain by Purcell's method.

Experimental Technique - Slot Impedance Measurement

Two experimental approaches were used to determine the slot impedance. The principal difference between these is in the method of terminating the guide.

In the first approach the guide section was terminated by a "wood load" of impedance approximately equal to the guide characteristic impedance. The small reflection from this load was reduced by means of a matching unit between it and the slot bearing section.

The klystron and modulated power supply controls were adjusted to produce the required signal in the guide. By adjusting the modulator frequency maximum response from the tuned amplifier was obtained. The signal strength in the guide was varied to a convenient value by means of the attenuator shown between the Klystron and guide section.

The adjustable probe in the standing wave detector when extended too far into the fields of the guide acted as a discontinuity causing a reflected wave component. In order to reduce this reflection a minimum depth of penetration by the probe was used. Having set the probe depth it was left unchanged for each set of experiments.

Slotted guide sections were of lengths equal to odd multiples of one quarter guide wave lengths. For these particular lengths the reflections due to couplers would be out of phase with each other, and would tend to cancel.

Several guide sections of the same length were constructed. One section was without a slot. The other sections formed three sets having a variation in slot length, width and angle of orientation respectively, all centered on the center line of the broad wall of the guide.

With the standard unslotted guide section inserted between the standing wave detector and the "wood load" the standing wave in the guide was taken. The standard section was replaced by the slotted section and the new standing wave obtained. The change in position and magnitude of the standing wave was due to the presence of the slot.

From the experimental data the series effective impedance of the "wood load" and slotted section was obtained. This approach contained the complication of having the two impedances in series giving rise to difficulty in determining their phase relationship and actual impedances.

In view of the difficulties encountered using a "wood load" guide termination a second experimental approach was used. For this method the guide was terminated by means of the short circuiting device described already as part of the apparatus.

From the field configuration for the T.E.$_{10}$ mode it may be noted that when the guide section is terminated by means of a short circuiting device the position of

maximum electric field intensity is an odd multiple of one quarter guide wave lengths distance from the short. The position of maximum charge flow in the guide wall due to the magnetic field effect will be found at a distance of an even multiple of one quarter guide wave lengths from the short.

The technique followed was to use a standard guide section bearing a very small opening, at the guide broad wall centerline, through which a probe could be inserted. The position of the short circuiting plunger relative to the probe was altered until the probe was at a point of minimum electric field intensity. The short was fixed in this position. Standard sections bearing slots at the position at which the probe had been inserted were substituted for the standard section. The slots as positioned were at a point of normal maximum charge flow in the guide wall, and interrupted this flow. Under that condition the slot series impedance effect acted as a termination for the guide. The standing wave magnitude and shift relative to that of the standing wave found in the absence of a slot enabled the determination of the slot series impedance.

The shorting plunger was moved a quarter of a guide wave length, thus placing the slot at a point of maximum electric field normal to the slot opening. In this position the slot shunt conductance characteristic was determined.

Since the slot was placed symetrically about the guide broad wall centerline it was found, as expected, that the shunt conductance was zero and therefore did not cause any change in the magnitude or position of the standing wave.

Thesis Data and Discussion

(1) Wave guide dimensions

$a = 0.898$ ins $= 2.280$ cms

$b = 0.40$ ins $= 1.02$ cms

(2) Cut off wave length

$$\lambda_c = 2a$$

$$\lambda_c = 4.56 \text{ cm}$$

(3) Wave length ih the guide measured by means of the standing wave detector.

$$\lambda_g = 4.44 \text{ cm.}$$

(4) Wave length in the unbounded dielectric obtained from

$$\lambda_g = \frac{\lambda_1}{\sqrt{1 - \frac{(\lambda_1)^2}{(\lambda_c)^2}}}$$

$$\lambda_1 = 3.180 \text{ cm}$$

(5) Frequency f = 9,434 megacycles

(6) For calibration of the cavity frequency meter, a reading of 163.5 corresponds to 9434 mc. To calibrate for frequency add 9270.5 to the dial feading.

The frequency of oscillation was kept constant at 9,434 mc, as accurately as possible, throughout the experiments.

(7) The characteristic impedance of the guide

$$Z_o = \sqrt{\frac{\mu_1}{\epsilon}}\, 377 \; \frac{\lambda_g}{\lambda_1} = 526 \text{ ohms}$$

The experimental observations recorded during the investigation are presented in graphical form. Each actual reading is marked as a point on one of the curves.

With the guide terminated by means of the wood load standing waves for slots of varying length, width or angle of orientation with the Z axis were obtained and are shown Figs. 8 9 and 10. In view of the fact that the crystal detector obeys the square-law relationship it was necessary to take the square root of the ratio of the minimum to maximum of the detected standing wave, to obtain the actual standing wave ratio. Having already determined the guide characteristic impedance Zo, and knowing that the slot impedance acts in series with Zo, the total effective impedance Z_L was found. These calculated values are shown in Figs. 11 and 12.

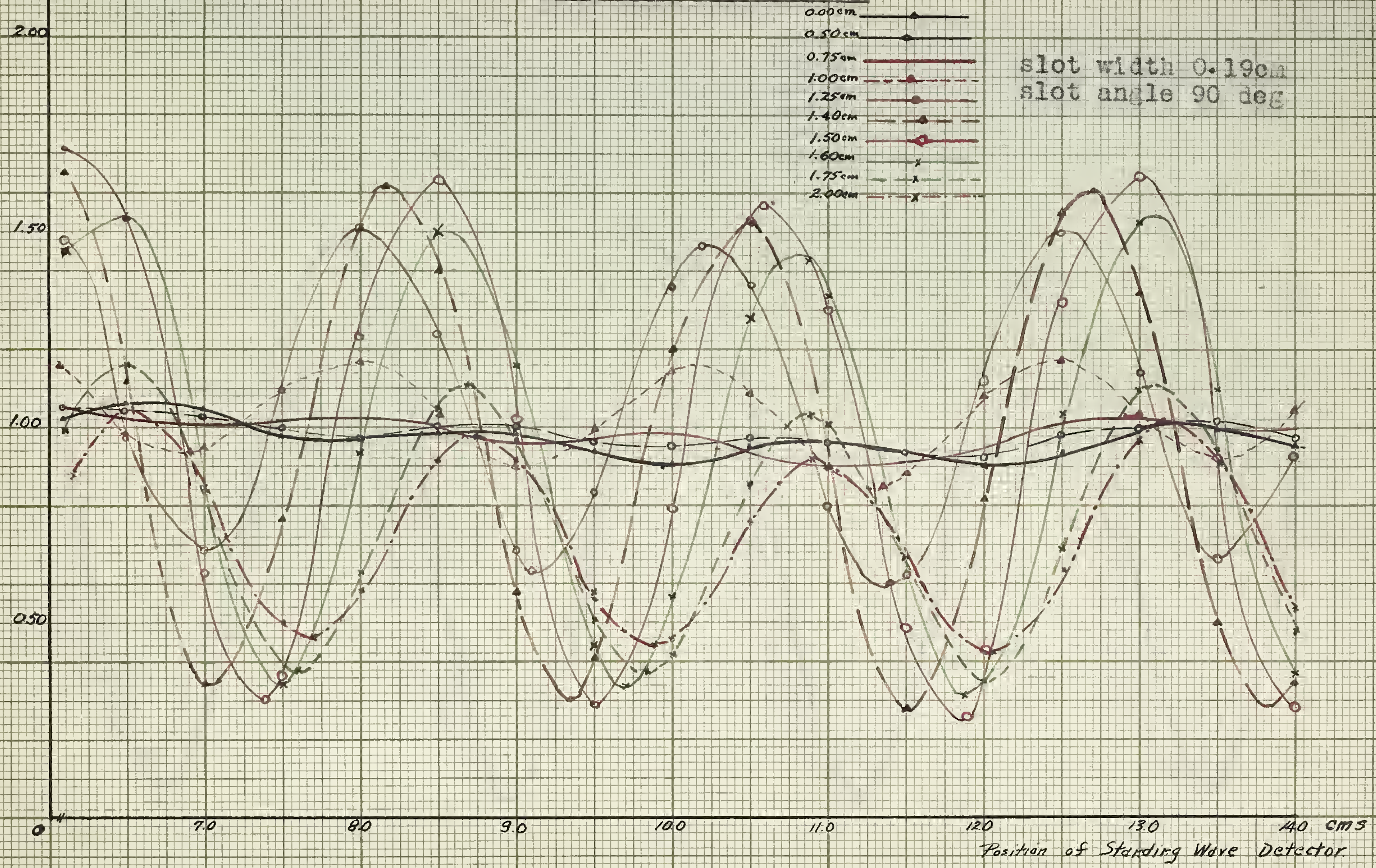
The narrow slot had a maximum impedance for a length slightly less than $\lambda_1/2$ and an angle of 90° to the Z axis. Difficulty was found in trying to separate Zo and the impedance of the slot, having determined the total effective impedance.

A second experimental approach was made with the guide terminated in a short circuit.

The standing wave ratios for slots of three different widths, varying length were obtained, and are shown in Fig. 14. In Fig. 15 the shift of the standing wave from its position for a slot of zero length located a multiple of half guide wave lengths from a shorted guide termination is plotted for variations in slot length.

Fig. 8. Standing Waves for Slots of Various Lengths.

Wood Load Termination



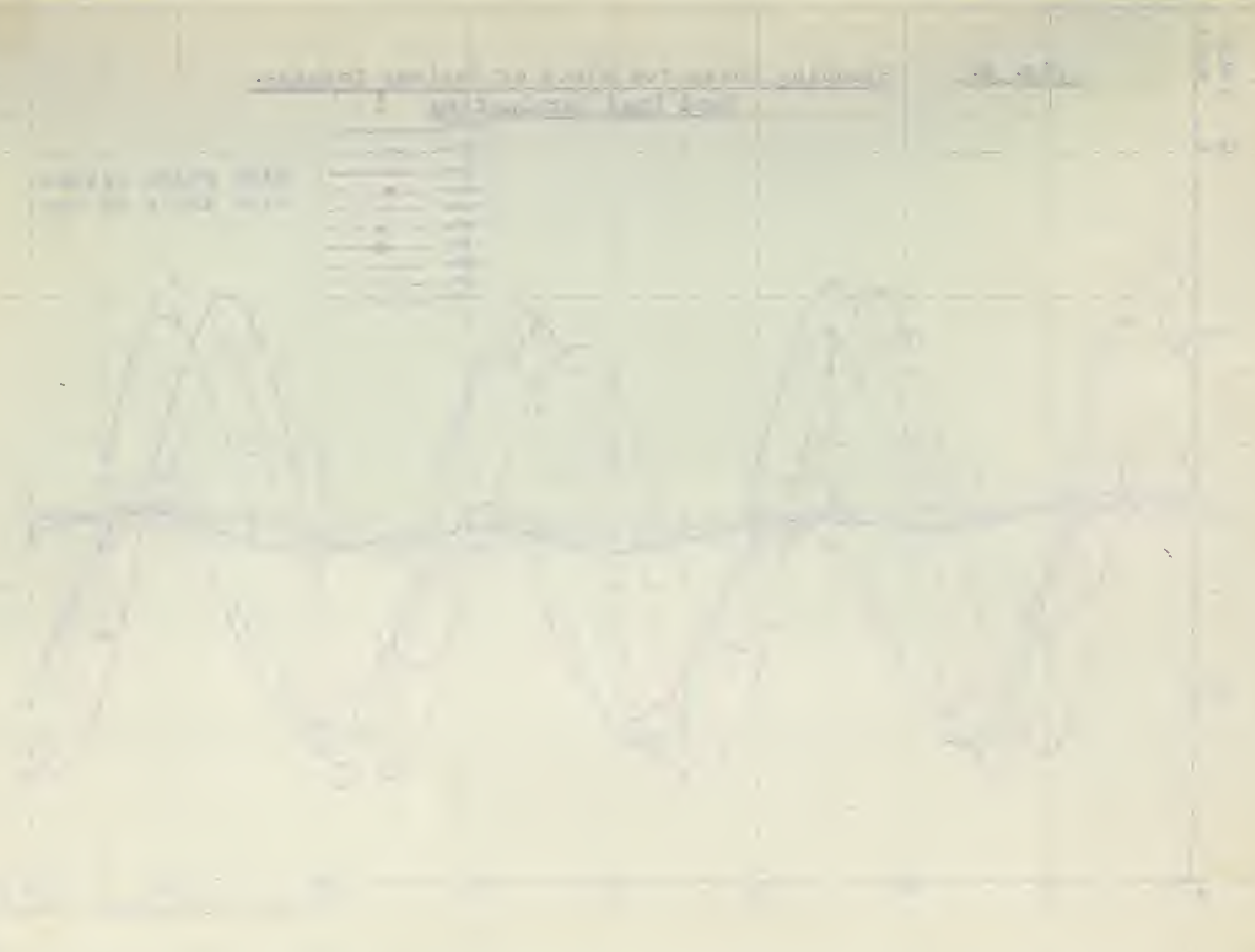


Fig. 9. Standing Waves for Slots of Various Widths

Wood Load Termination

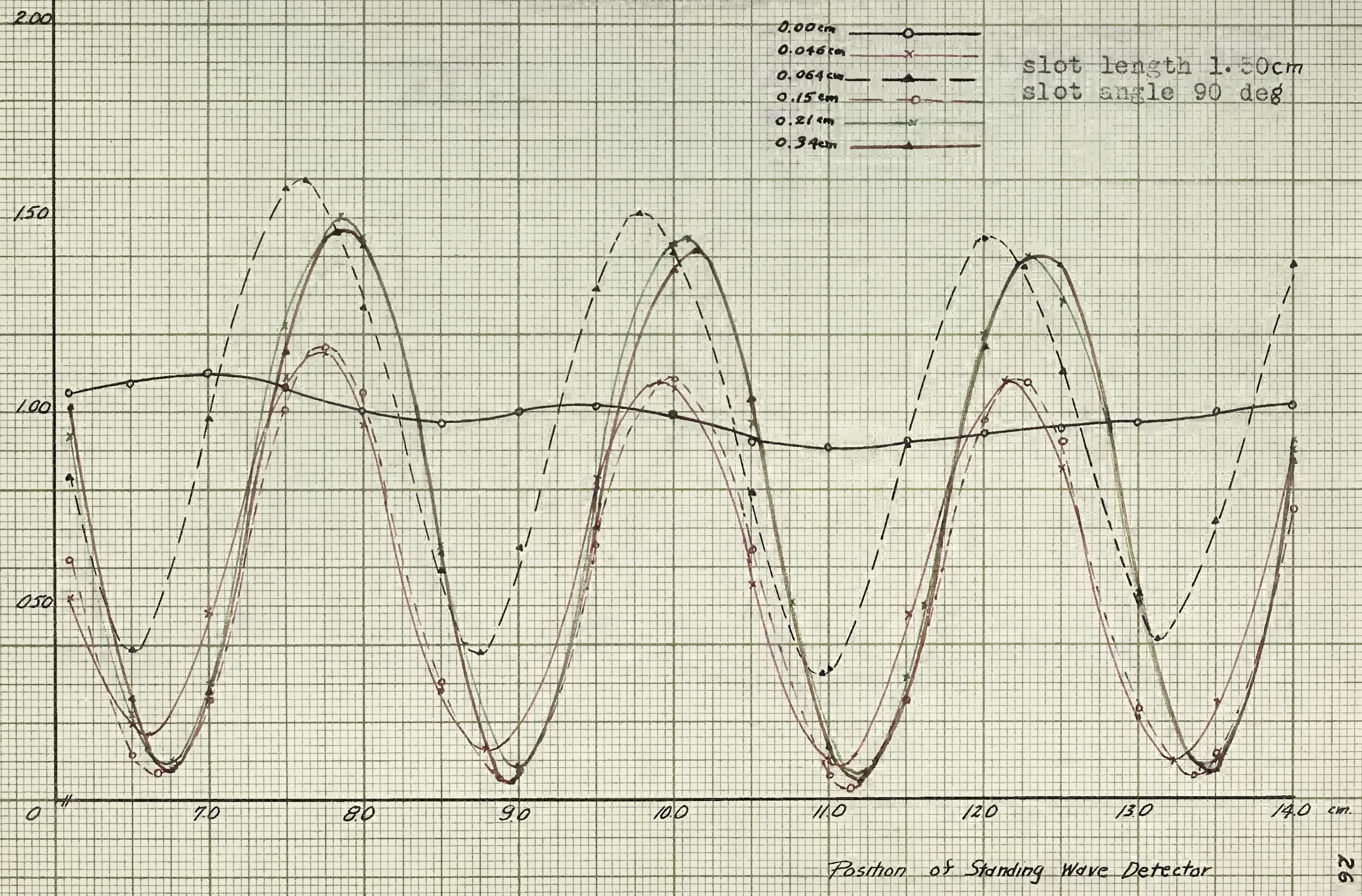


Fig. 10.

Standing Waves for Slots of Various Angles Relative to the Z Axis

Wood Load Termination

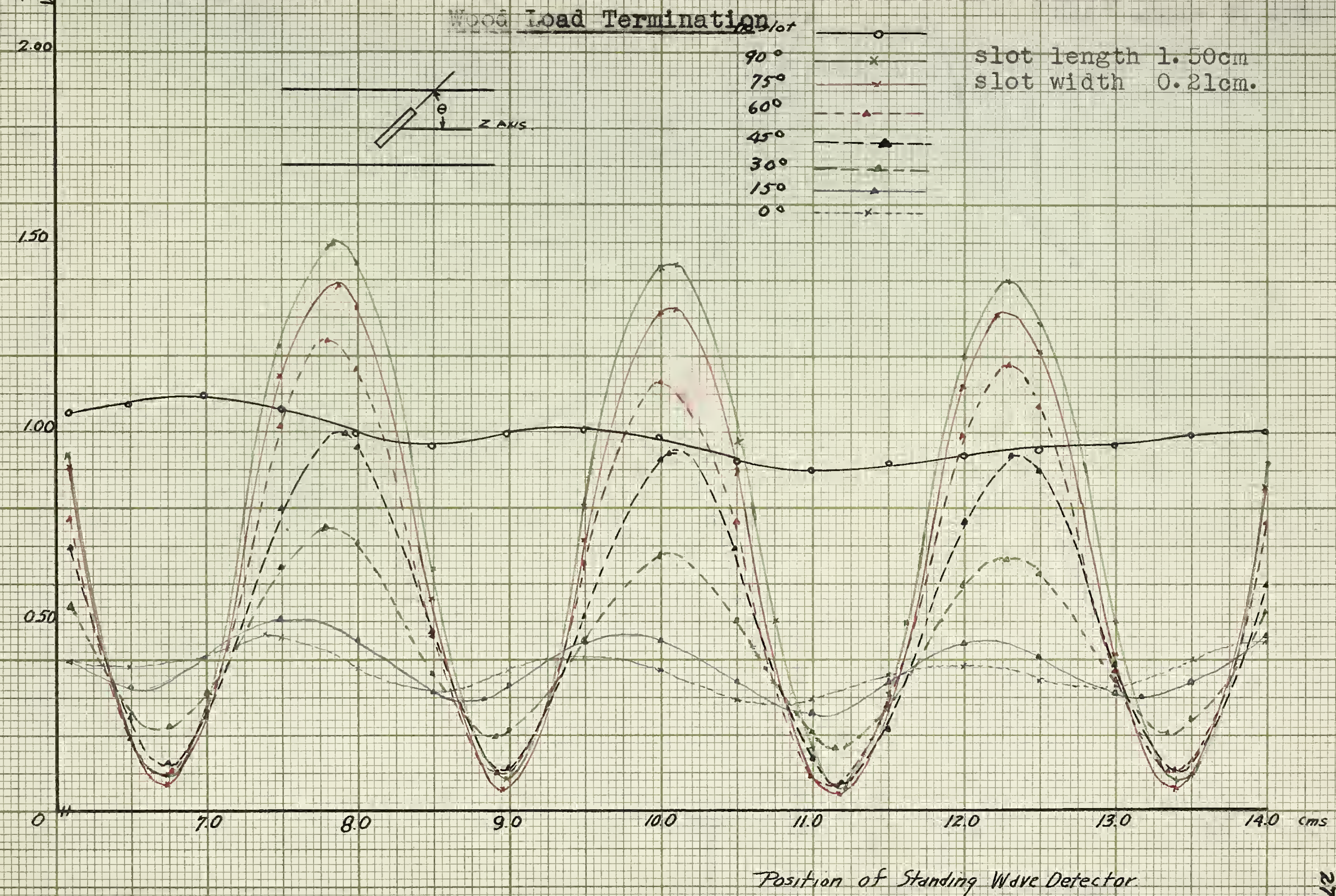


Fig. 11. Effective Total Impedance-- Slots of Various Lengths. Wood Load Termination

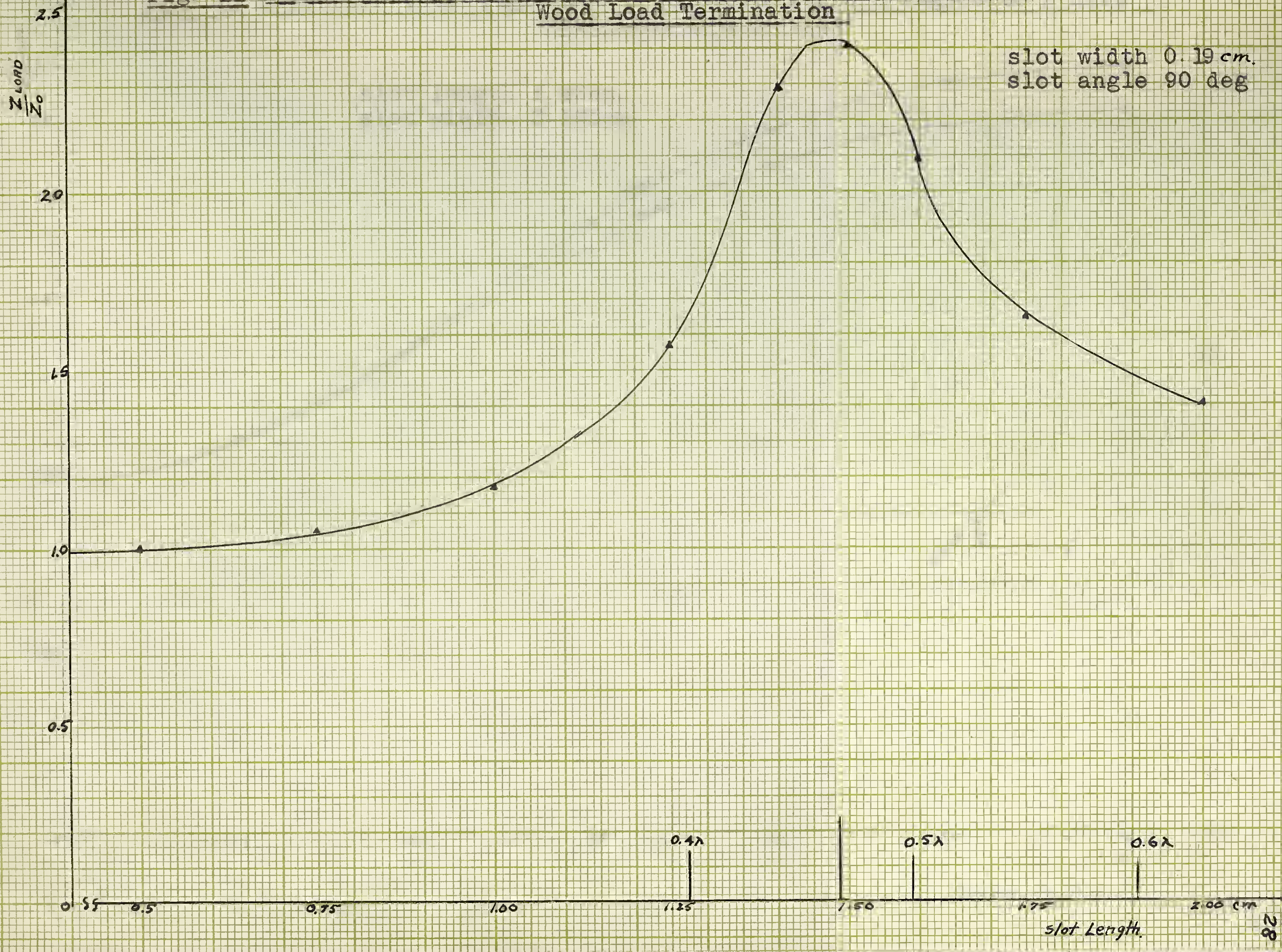


Fig. 12. Effective Total Impedance--- Slots of Various Angles to Z Axis
Wood Load Termination

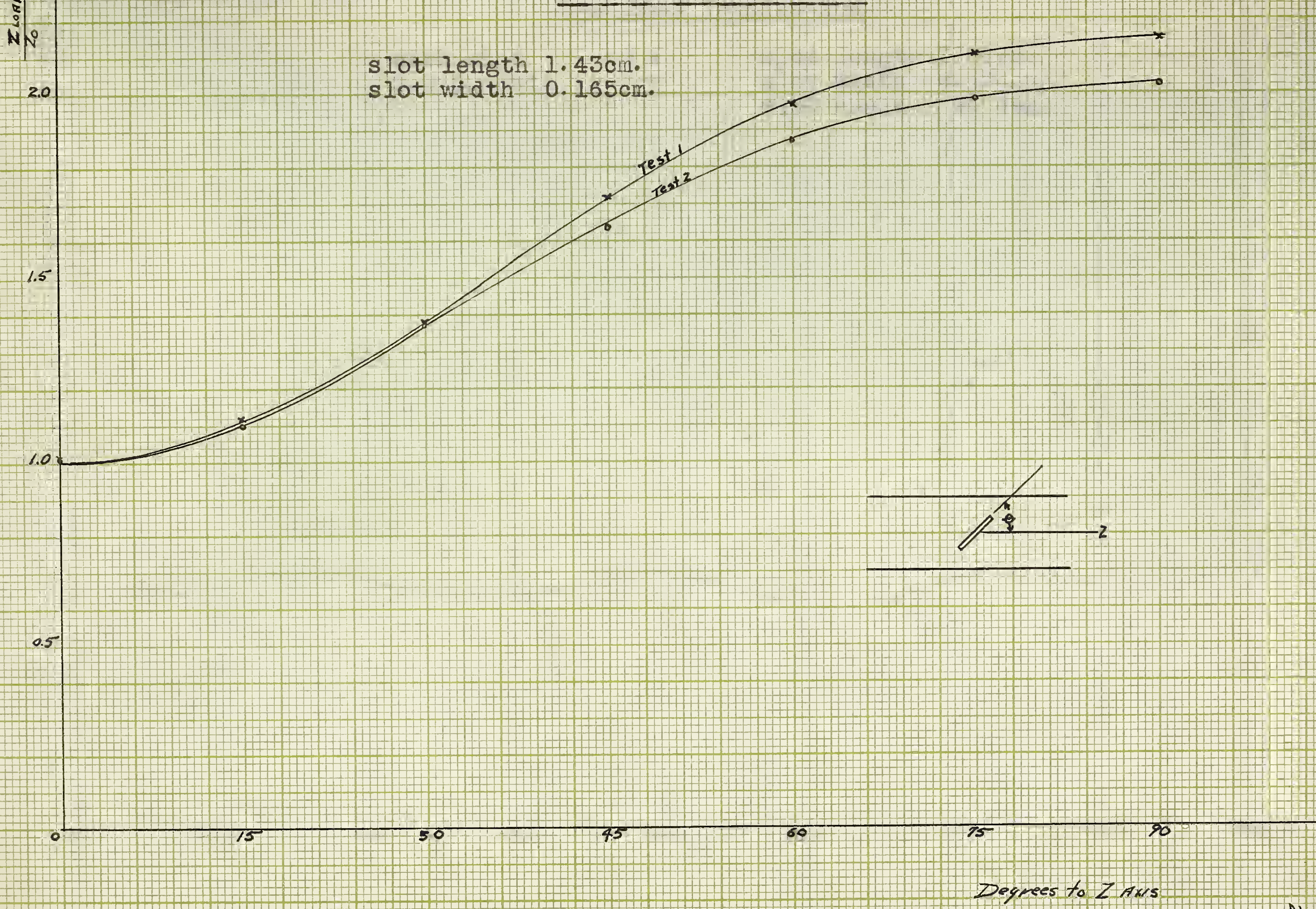
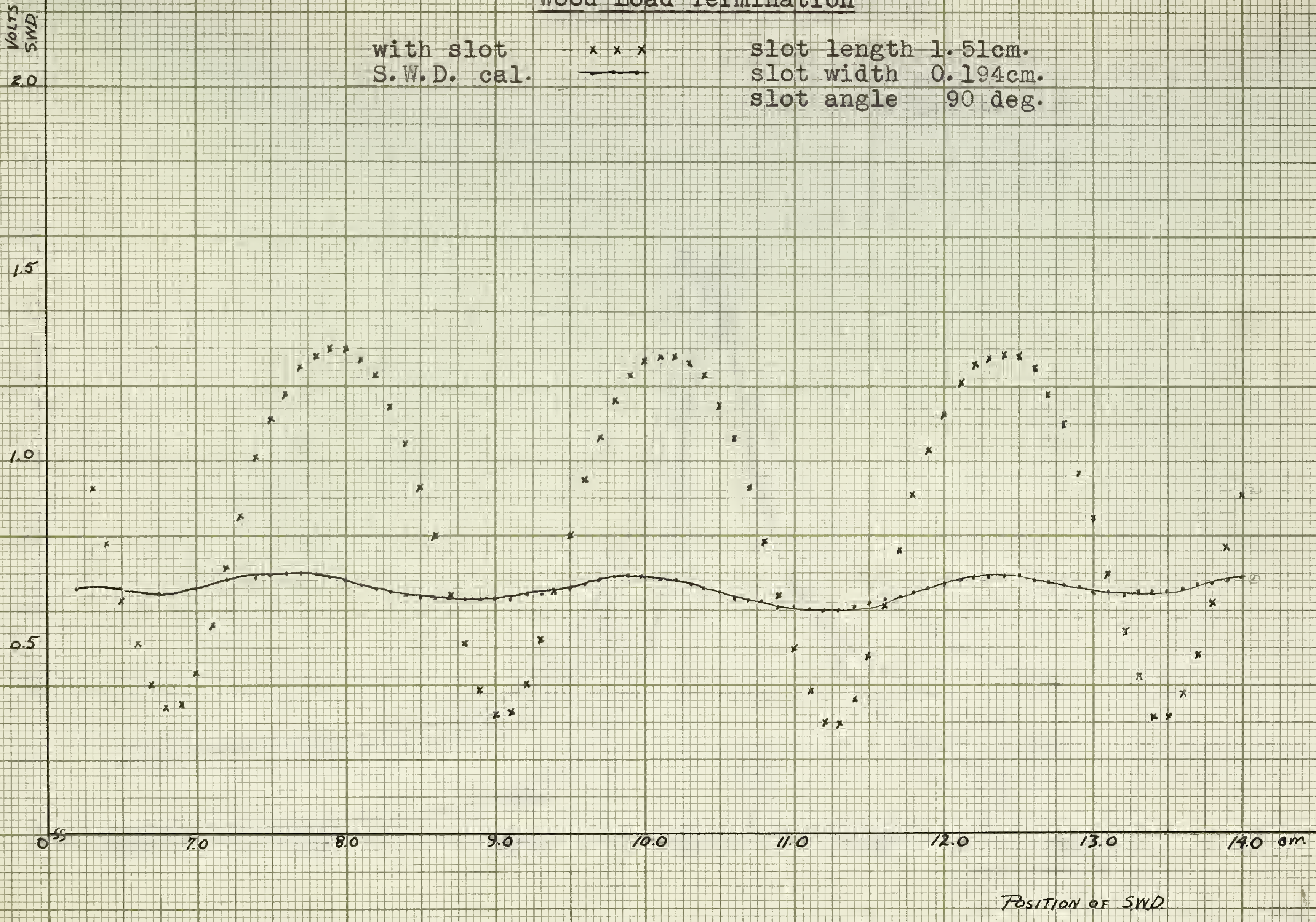


Fig. 13. Standing Wave for Accurately Machined Slot
Wood Load Termination



slot length 1.51cm.
slot width 0.194cm.
slot angle 90 deg.

Fig. 14. Standing Wave Ratio- Slots of Varying Length

Shorted Guide Termination

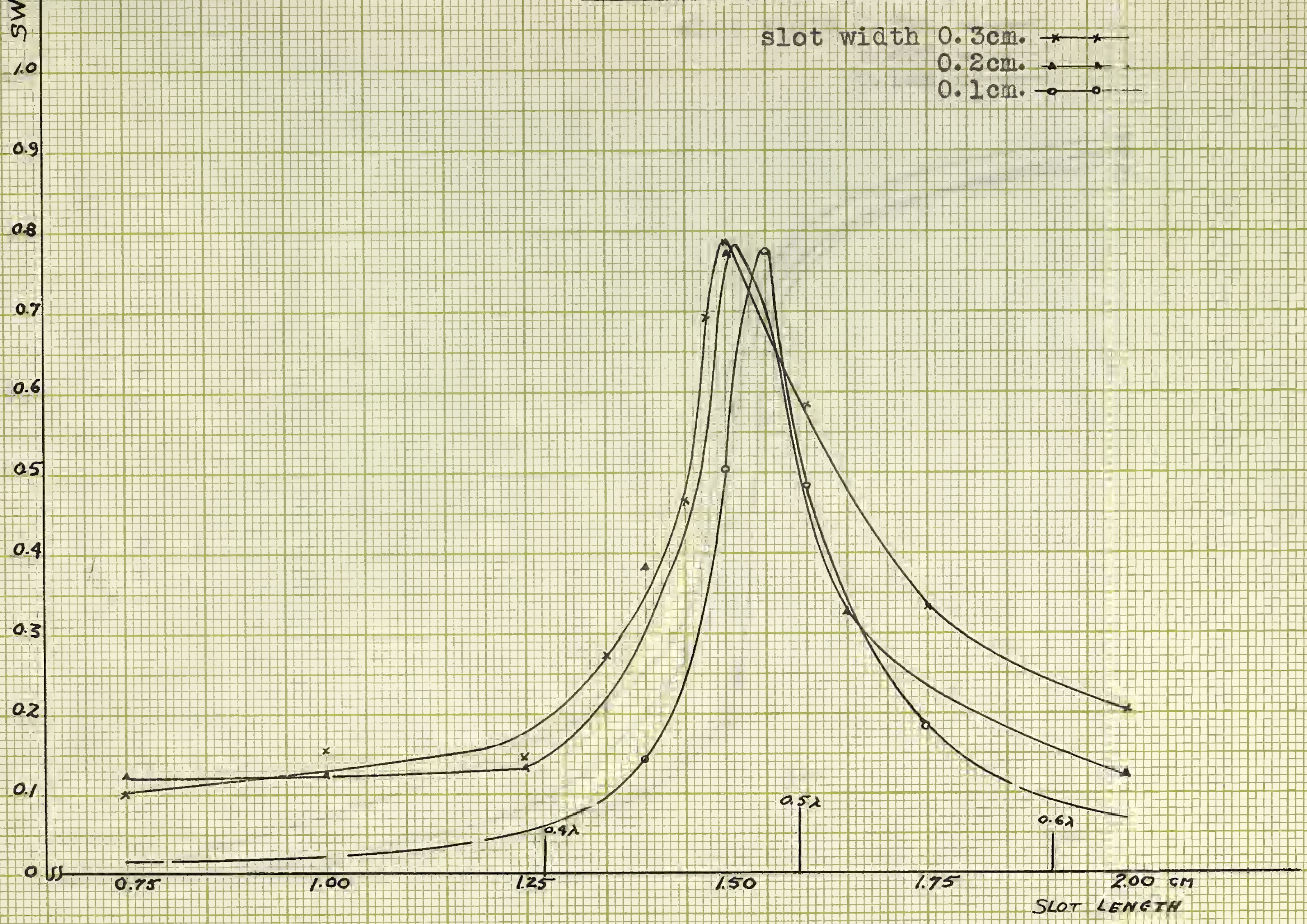
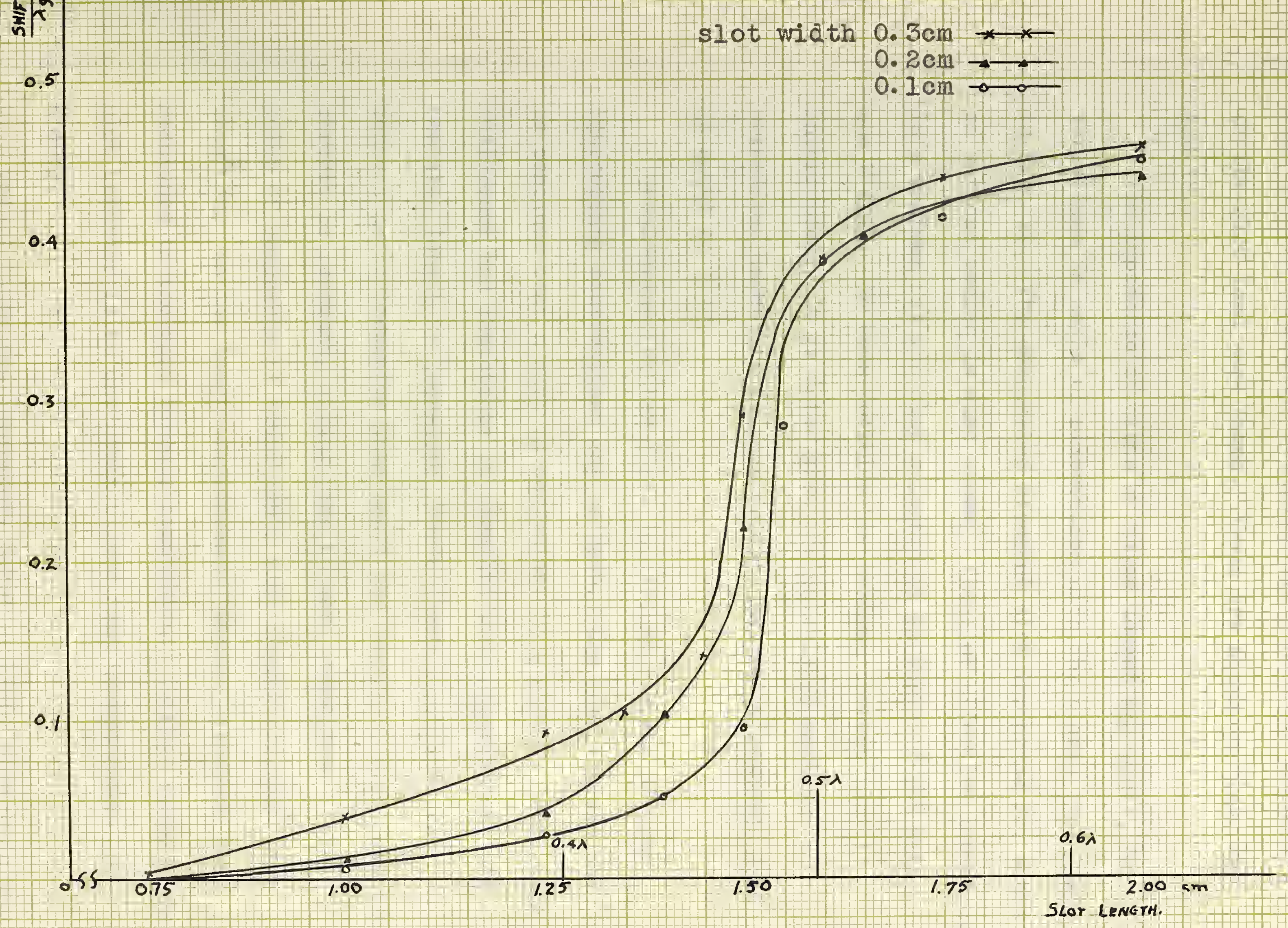


Fig. 15 Shift of Standing Wave Towards Load- Slots of Varying Length
Shorted Guide Termination



By means of the Smith Circular Transmission Line Chart Fig. 17, the impedance, resistive and inductive components of the slot load were found. These are shown in Figs. 16 and 18.

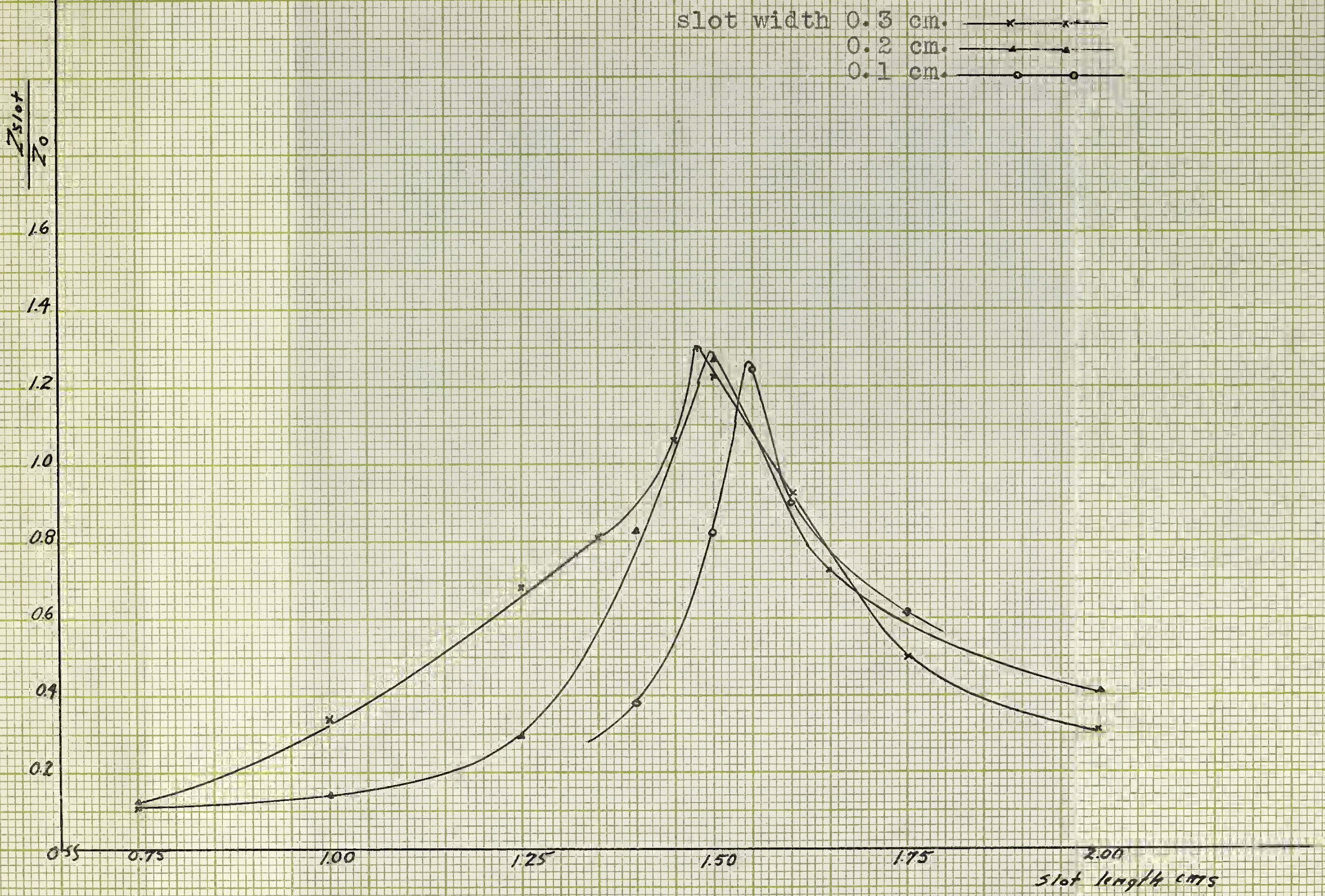
The impedance of slots of fixed length and width, for variations in angle of orientation with the Z axis are shown in Fig. 19. The calculated resonant slot impedance[9] for slots of various angles is also shown. The slot effective impedance is a maximum for the slot oriented at an angle of 90° with the Z axis. In this position the maximum current flow is interrupted. It is noted that the calculated maximum normalized impedance (a pure resistance) for a resonant slot is equal to 1.30.

Considering further Figs. 14, 15, 16, 17 and 18 some interesting observations may be made. The results lead one to conclude that a slot is equivalent to a circuit containing resistance and inductance in parallel with capacitance. As the slot length is increased, for a given width, the slot behaves as an inductive load until the length is such that the circuit is resonant, giving rise to zero reactance. This point of resonance is found for a slot length slightly less than $\lambda/2$. As the length is increased beyond resonance the reactance of the slot becomes capacitive. In this respect the slot behavior is as one would expect from transmission line theory.

9. - Vol 12 Radiation Laboratory Series - Micro Wave Antennae Theory and Design.

Fig. 16

Impedance of Slots - Varying Length.



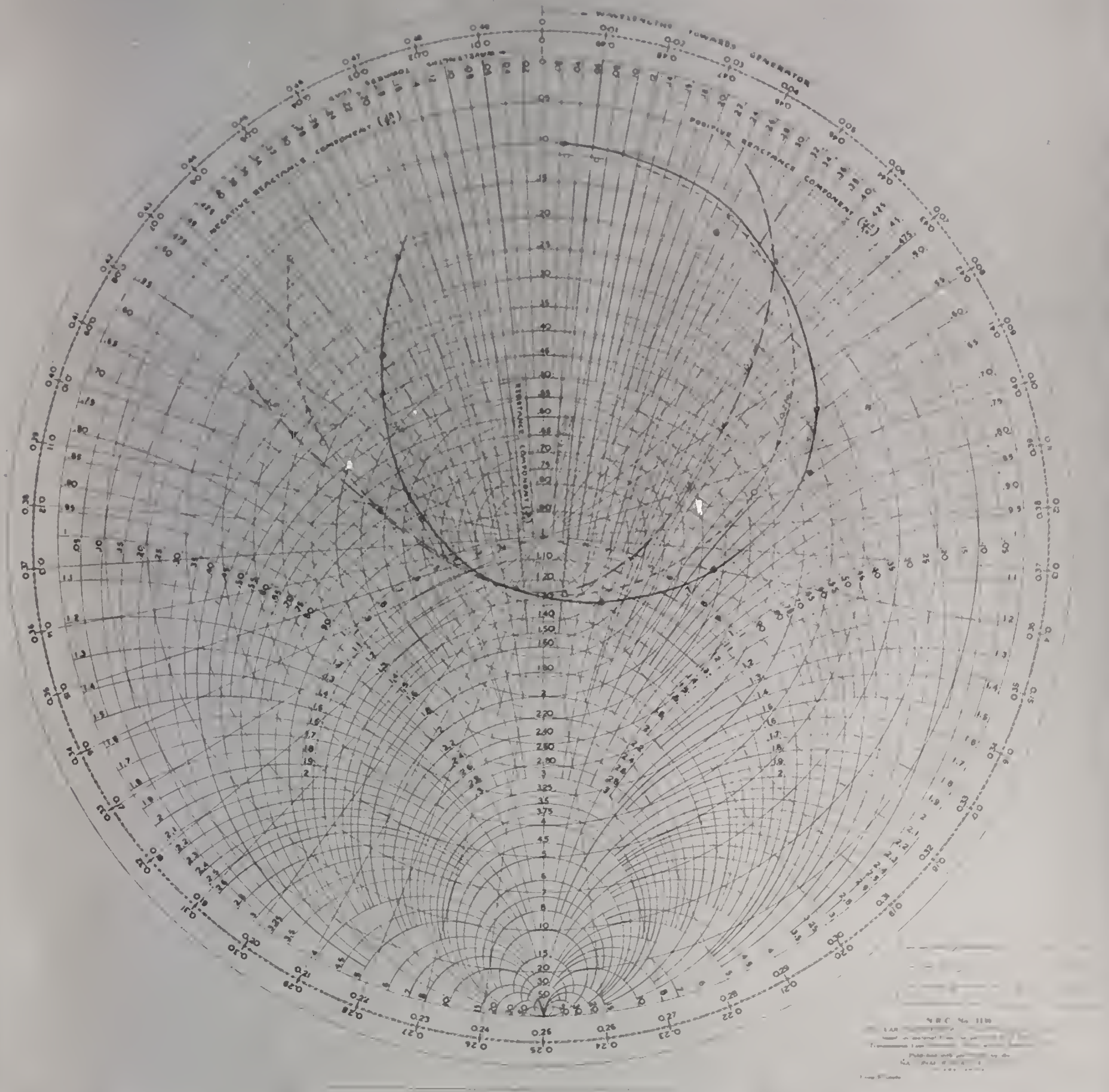
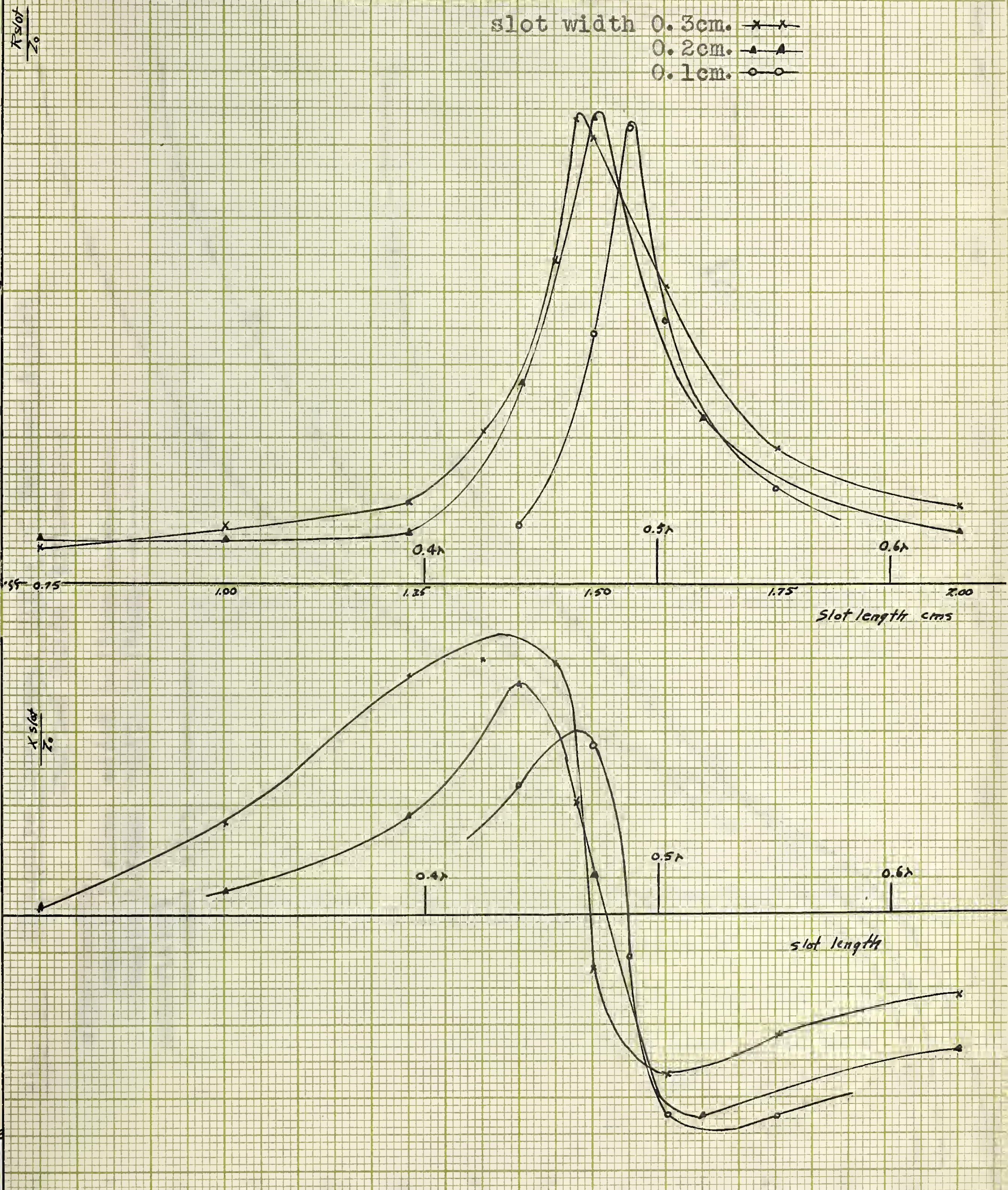


Fig. 17 Slot Impedance Diagram - Varying Slot Length

Fig. 18

Resistance and Reactance of Slots of Varying Length



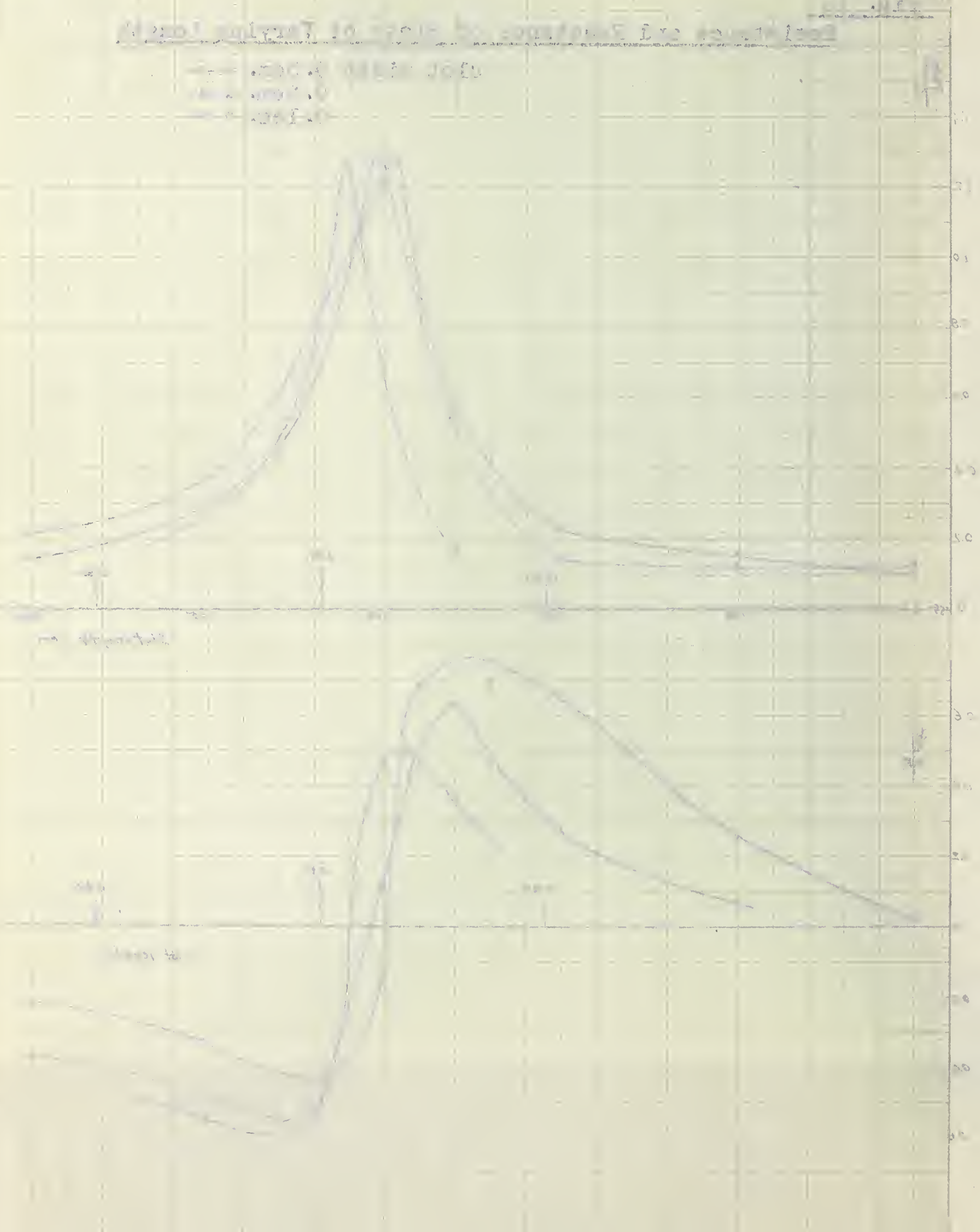
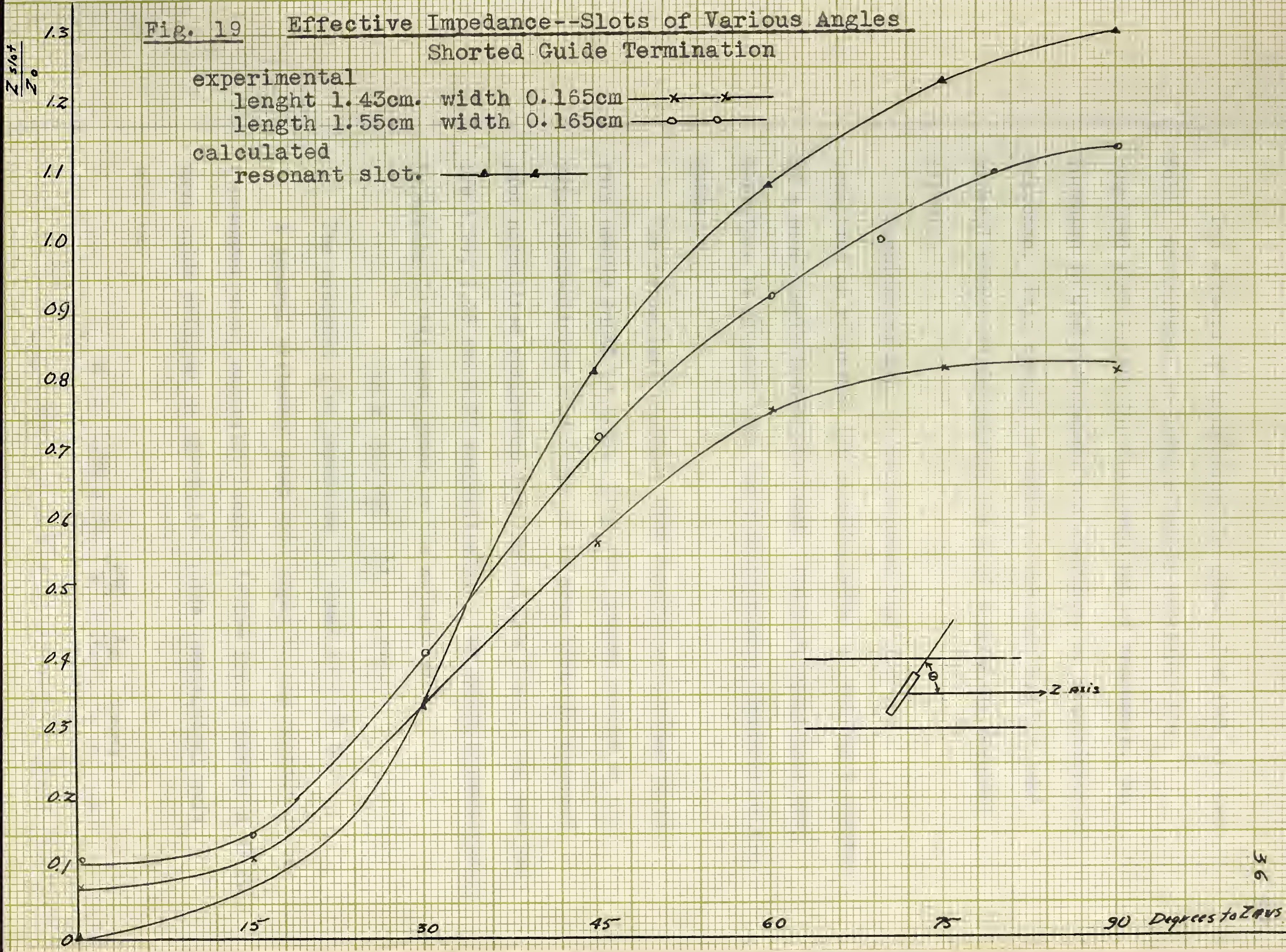


Fig. 19 Effective Impedance--Slots of Various Angles
Shorted Guide Termination



The effects of increasing the width of a slot are two fold. An increase in width slightly decreases the required slot length for the condition of resonance. An increase in width decreases the sharpness or sensitivity of response. This change in width of the slot has the same general effect as decreasing the Q of a parallel resonant circuit.

Considering Fig. 15 it is noted that for the condition of resonance the standing wave has shifted a quarter of a wave length toward the load. The slot resistance must therefore be greater than the characteristic impedance of the guide.

The normalized resonant slot impedance is found to be very nearly equal to 1.30. From the plotted values on the Smith Transmission Line Chart it is seen that the resonant slot normalized resistance for slot widths 3 mm, 2 mm, and 1mm are 1.29, 1.28 and 1.27 respectively. The guide characteristic impedance Zo has been given by the expression

$$Zo = 377 \sqrt{\frac{\mu_1}{\epsilon_1}} \; \frac{\lambda_g}{\lambda_1} \quad \text{ohms}$$

The resonant slot impedance is equal to 1.30 Zo.

A general statement that will apply to the resistance of a resonant slot, centrally located in the broad side of a TE 10 wave guide oriented at 90° to the guide longitudinal axis will be.

$$R = 1.30 \times 377 \sqrt{\frac{\mu_1}{\epsilon_1}} \; \frac{\lambda_g}{\lambda_1} \quad \text{ohms}$$

The frequency of the signal in the guide was varied, and the standing wave ratio obtained for a given slot, the guide terminated in a short circuit. It was necessary to adjust the position of the shorting device to maintain a distance of a number of half guide wave lengths between it and the slot.

The slot perimeter for the point of maximum Standing Wave Ratio, Fig. 21, is found to be very nearly equal to the wave length of the signal in free space.

In Fig. 22 the detected signal from the crystal square-law detector and amplifier is compared with the calculated signal. The plotted curves are almost identical, differing only slightly for the lower signal strengths.

The normalized resonant slot impedance value of 1.30 was obtained from the mathematical work of A. F. Stevenson[10] of the University of Toronto.

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10. Stevenson, A.F. - Theory of Slots in Rectangular Wave Guides, Special Committee on Applied Mathematics, National Research Council of Canada, 1944.

Fig. 20. Standing Waves for Accurately Machined Slot
Shorted Guide Termination

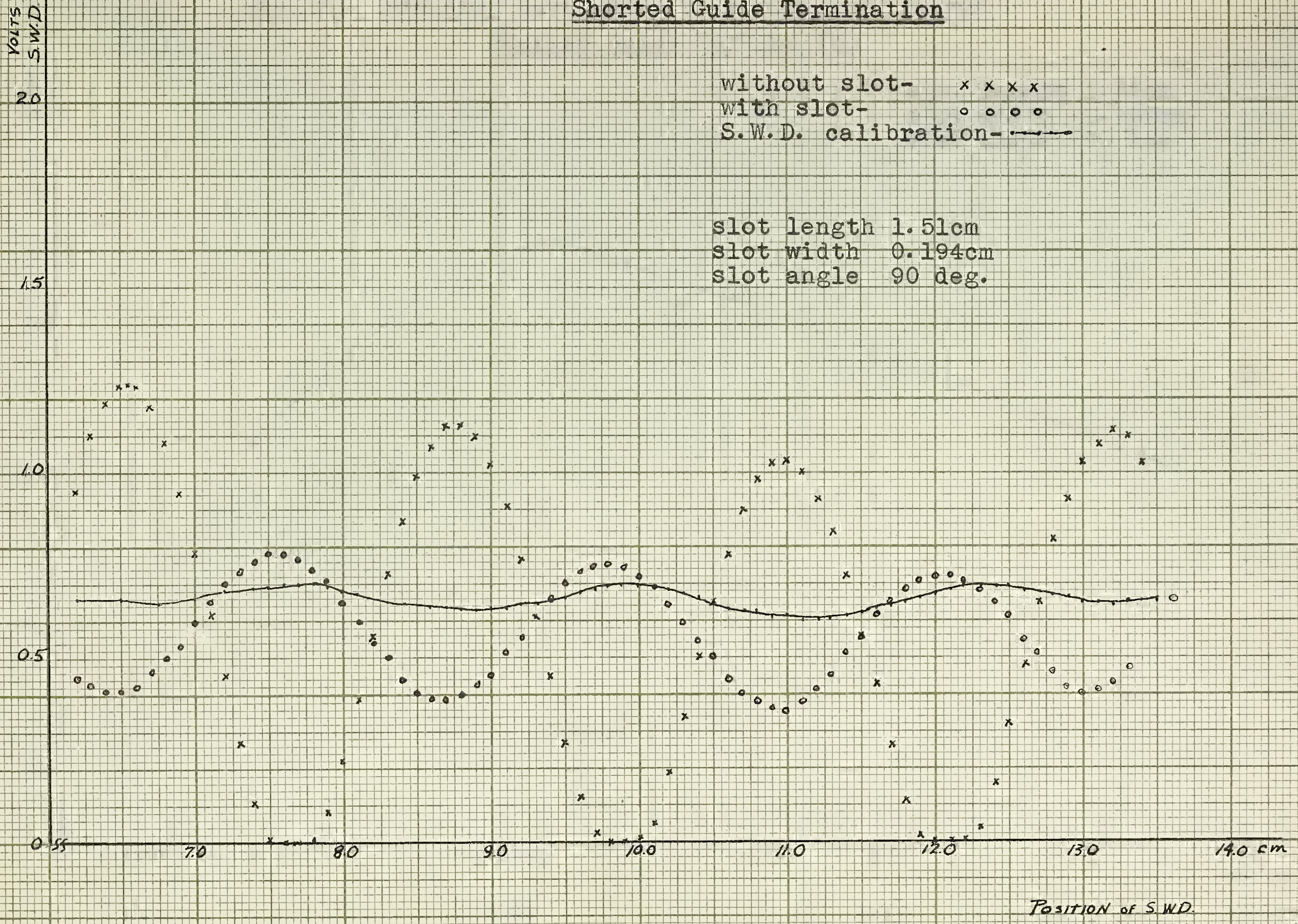
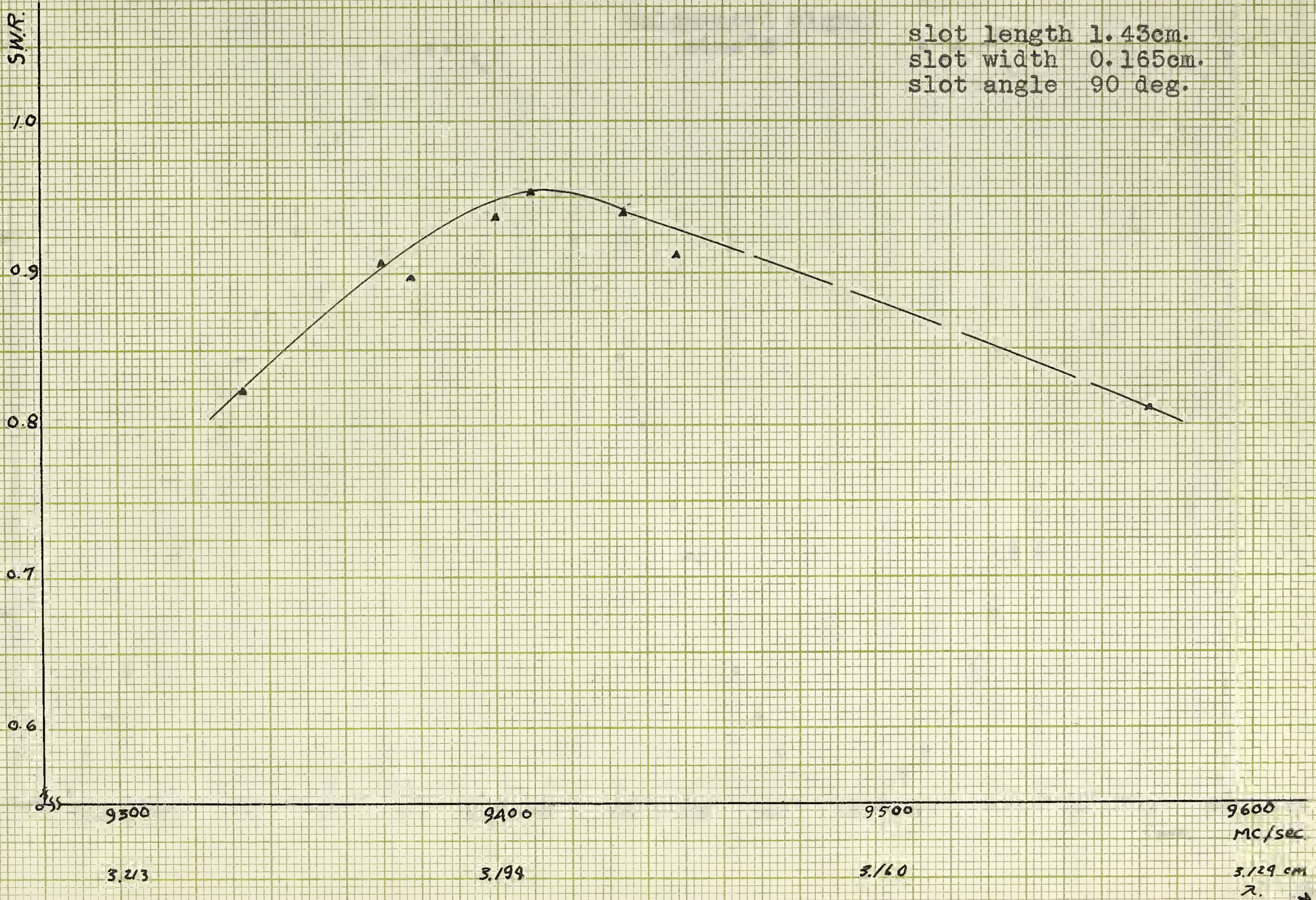


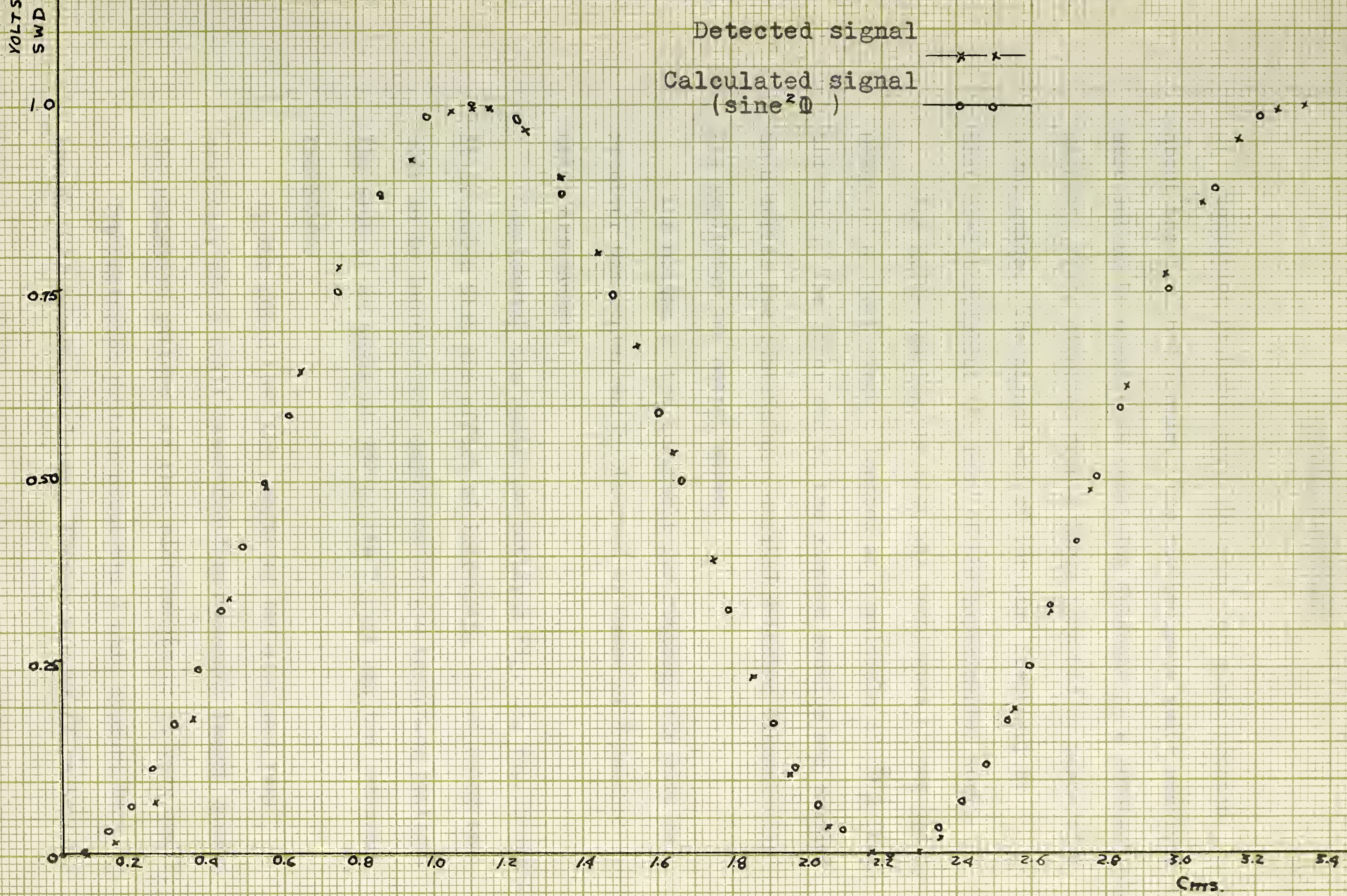
Fig. 21. Standing Wave Ratio vs Frequencyof Signal

Shorted Guide Termination



slot length 1.43cm.
slot width 0.165cm.
slot angle 90 deg.

Fig. 22. Calibration of Crystal- Square-Law Detector



SLOT RADIATION

Radiation patterns were obtained for slots rotated about the X, Y and Z axis. The slotted wave guide sections were set up to operate as receiving antennae in a constant electro magnetic field directed from a large horn fed by means of a 3 cm. guide. The signal was of the same frequency as that used throughout the rest of the experimental work.

The guide bearing the slot was terminated at one end by means of a short circuit located at a multiple of $\lambda_g/2$ from the slot. The other end of the slotted section was coupled to a series tee containing a crystal detector connected to the amplifier and output meter.

The motion of the turntable for rotating the slot as receiver was conveniently observed by means of a selsyn motor arrangement.

Considering the radiation patterns Fig. 23, 24, 25 and 26 it is noted that the effect of increasing the width of the slot is to increase the magnitude of the radiation pattern. The slot at an angle of 90° to the Z axis has the greatest radiation.

It was noted that the length of the slot was very critical, and a small departure from resonant length caused the radiation pattern for that slot length to be very small.

The radiation pattern about the Y axis appears very broad, with pronounced lobes. This broadness of pattern is

Fig. 23. Radiation Patterns for Slots of Different Lengths

(rotated about the X axis, E perpendicular to X)

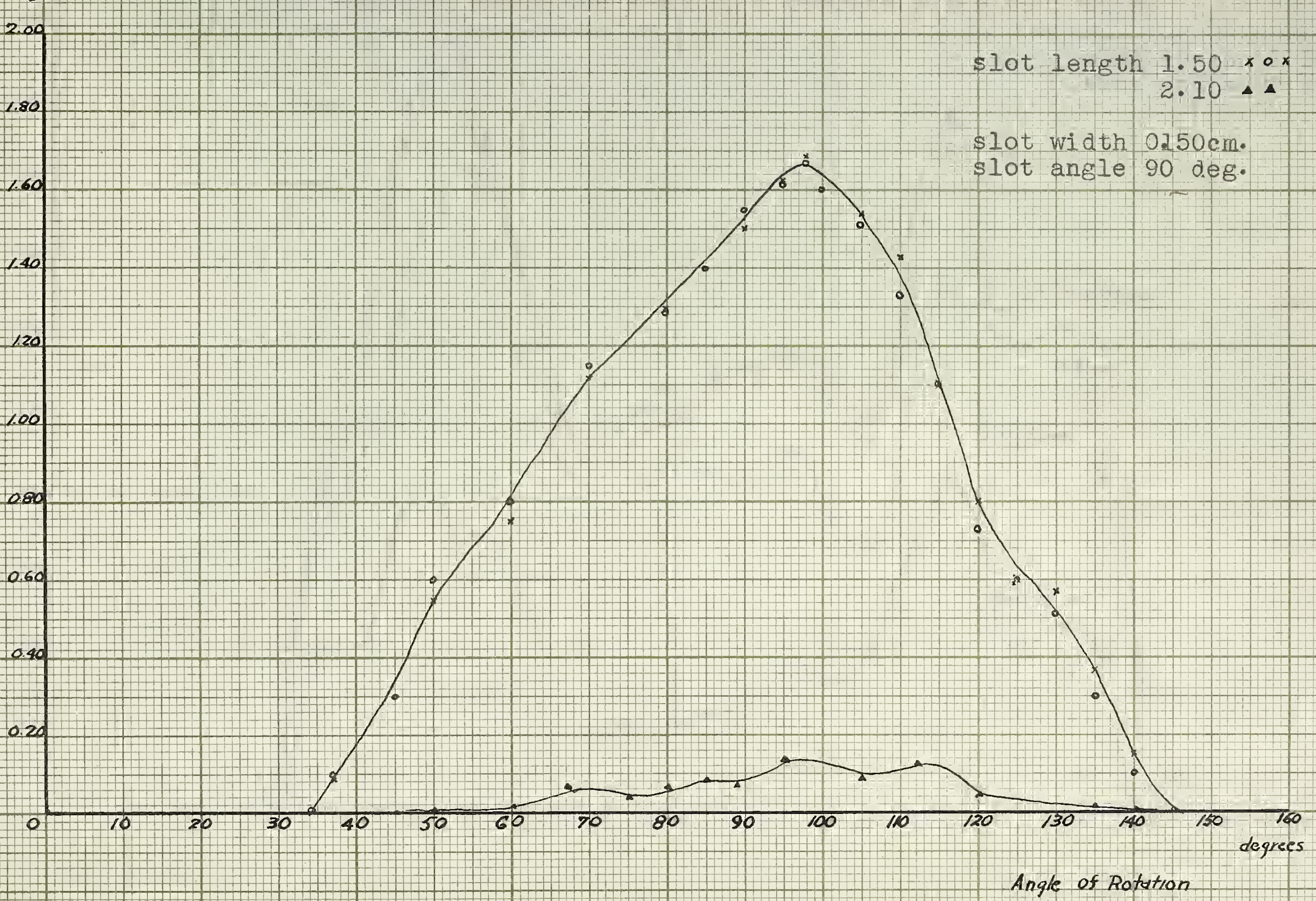


Fig. 24.

Radiation Patterns for Slots of Various Widths

(rotated about the Y axis, E perpendicular to Y axis)

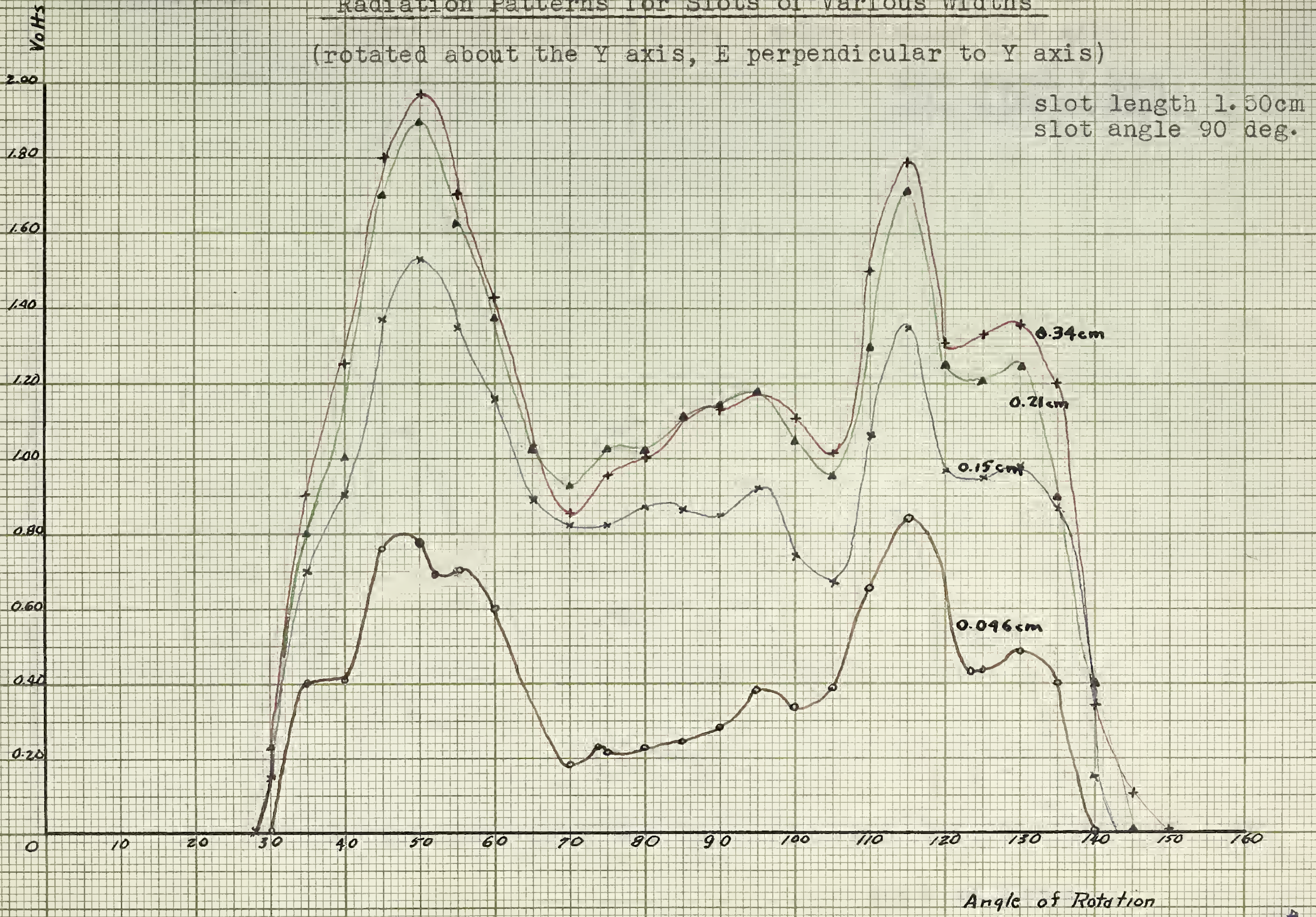
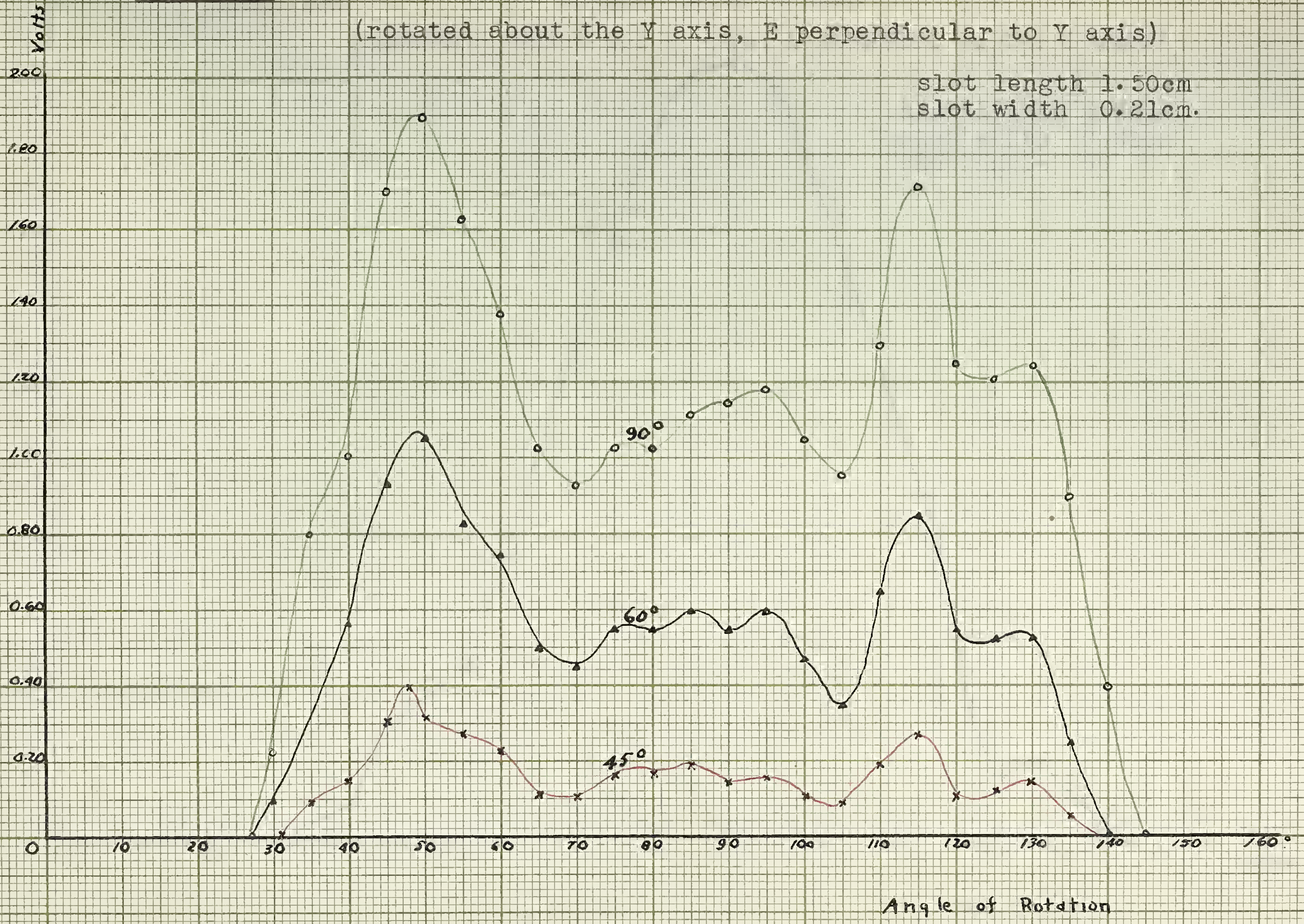


Fig. 25. Radiation Patterns for Slots of Various Angles

(rotated about the Y axis, E perpendicular to Y axis)

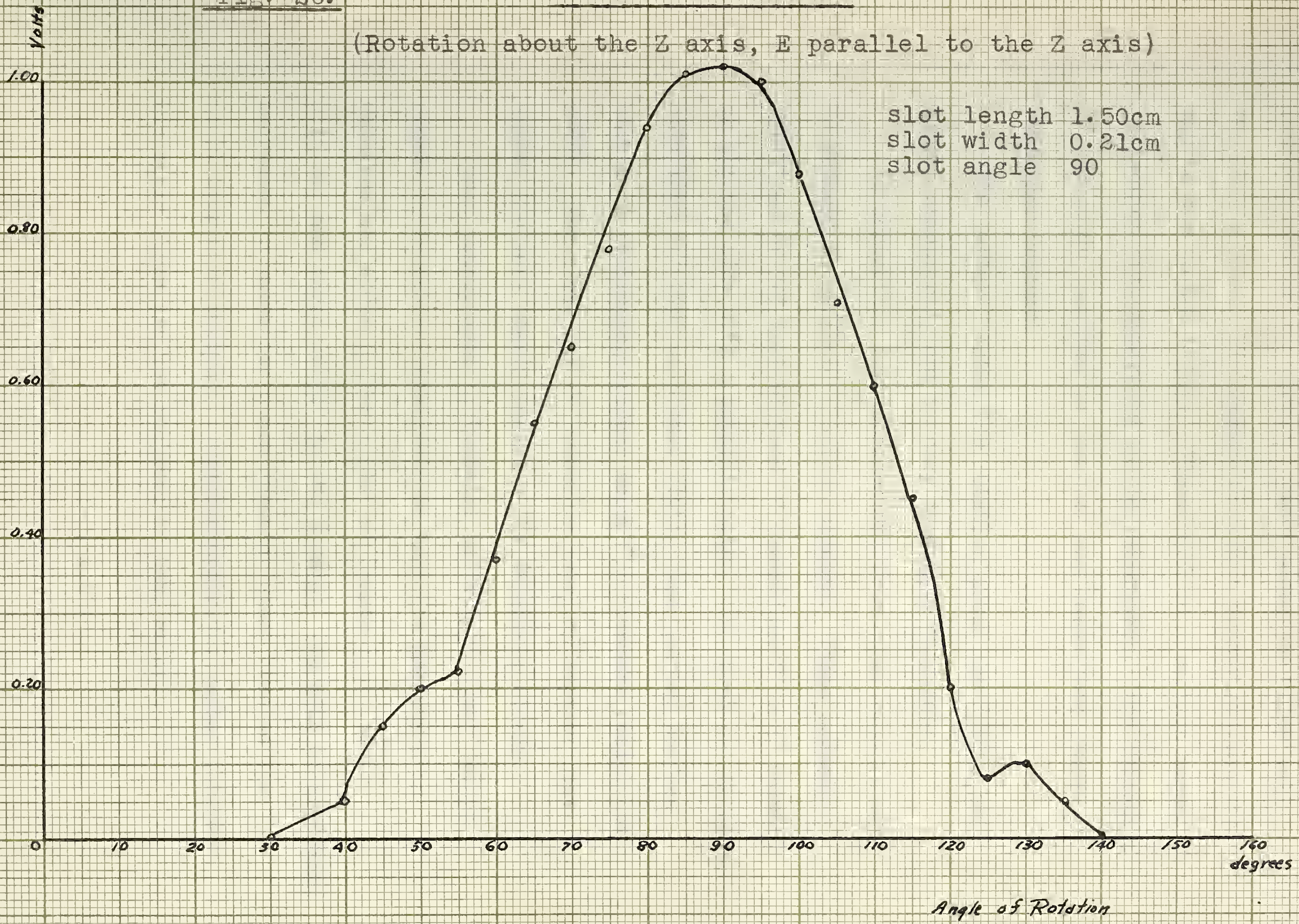


slot length 1.50cm
slot width 0.21cm.

Fig. 26.

Radiation Pattern

(Rotation about the Z axis, E parallel to the Z axis)



slot length 1.50cm
slot width 0.21cm
slot angle 90

probably due to the electric field along the guide wall beyond the slot. The departure from a symetrical pattern may be due to two things. There will be a certain amount of reflection from apparatus in the laboratory. The closeness of the guide couplers to the slot may cause some change in radiation pattern.

The patterns taken for rotation about the Z axis is almost symetrical, and is very directive in nature.

In laboratory work reflections from other objects may be reduced by means of a set of screens. These screens consisted of 3/8 inch plywood of dimensions 2' x 3' painted on the one side with a metallic paint, and faced on the other side with 377 ohm resistance cloth. The painted surface acts as a reflecting surface about $\lambda/4$ from the resistance cloth. The cloth has an impedance equal to that of free space, and very nearly equal to the impedance of air.

Gain measurement by Purcells Reflecting Plate Method proved to be rather unreliable in that the maximum gain obtained was about 4, for a slot of length 1.50, width 0.15 cm. and angle of 90° to the Z axis. The gain measurements decreased in value for a non resonant slot. Due to the small degree of accuracy in measurements the values obtained for other slots are not included in this report.

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Accuracy of Results.

A general statement regarding the accuracy of the impedance measurement experimental results is believed to be more appropriate than an estimate of the probable error.

The voltmeter error range as given by the manufacturer is ± 5%. From the crystal calibration curve Fig. 22 one may observe that the theoretical and experimental behavior of the detector are almost identical except for small departures at low signal strengths.

The slot dimensions were carefully measured using an automotive feeler gage, and micrometer.

The results obtained for normalized resonant slot impedance using the Smith Impedance Diagram are 1.29, 1.28 and 1.27. These compare favorably with the theoretical value of 1.30.

NOMENCLATURE

E - electrical intensity
H - magnetic intensity
ε - dielectric constant of air
μ - permeability in air
ρ - charge density
σ - electrical conductivity
λ - wave length
λ_g - wave lengths in the guide
λ_c - cut off wave length
γ - propagation constant
α - attentuation constant
β - phase constant
a - guide width
y - displacement of slot from guide center line
ω - angular velocity
R - coefficient of reflection
SWR - standing wave ratio
G - gain by Purcell's method
d - distance between slot and reflecting plate.

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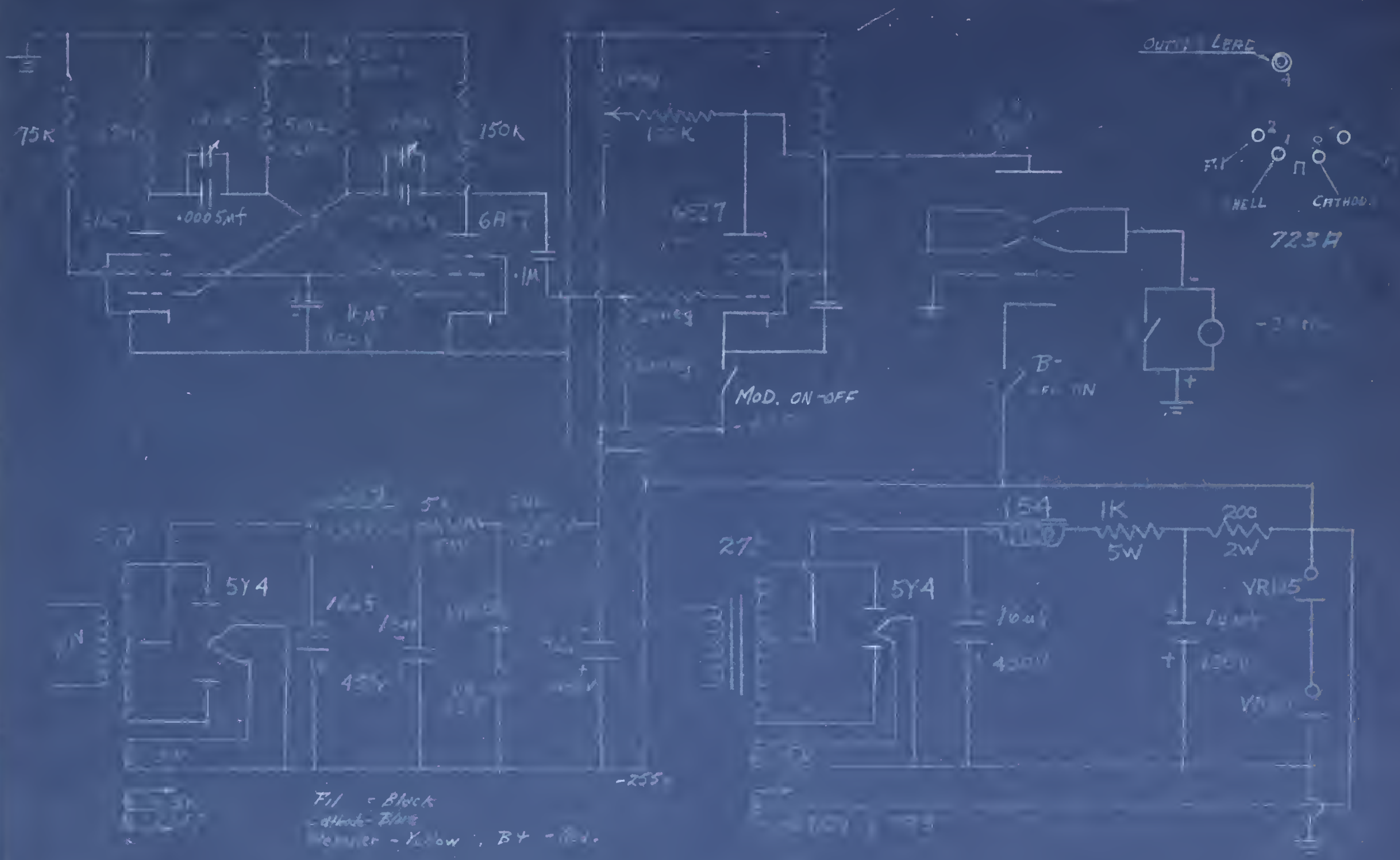
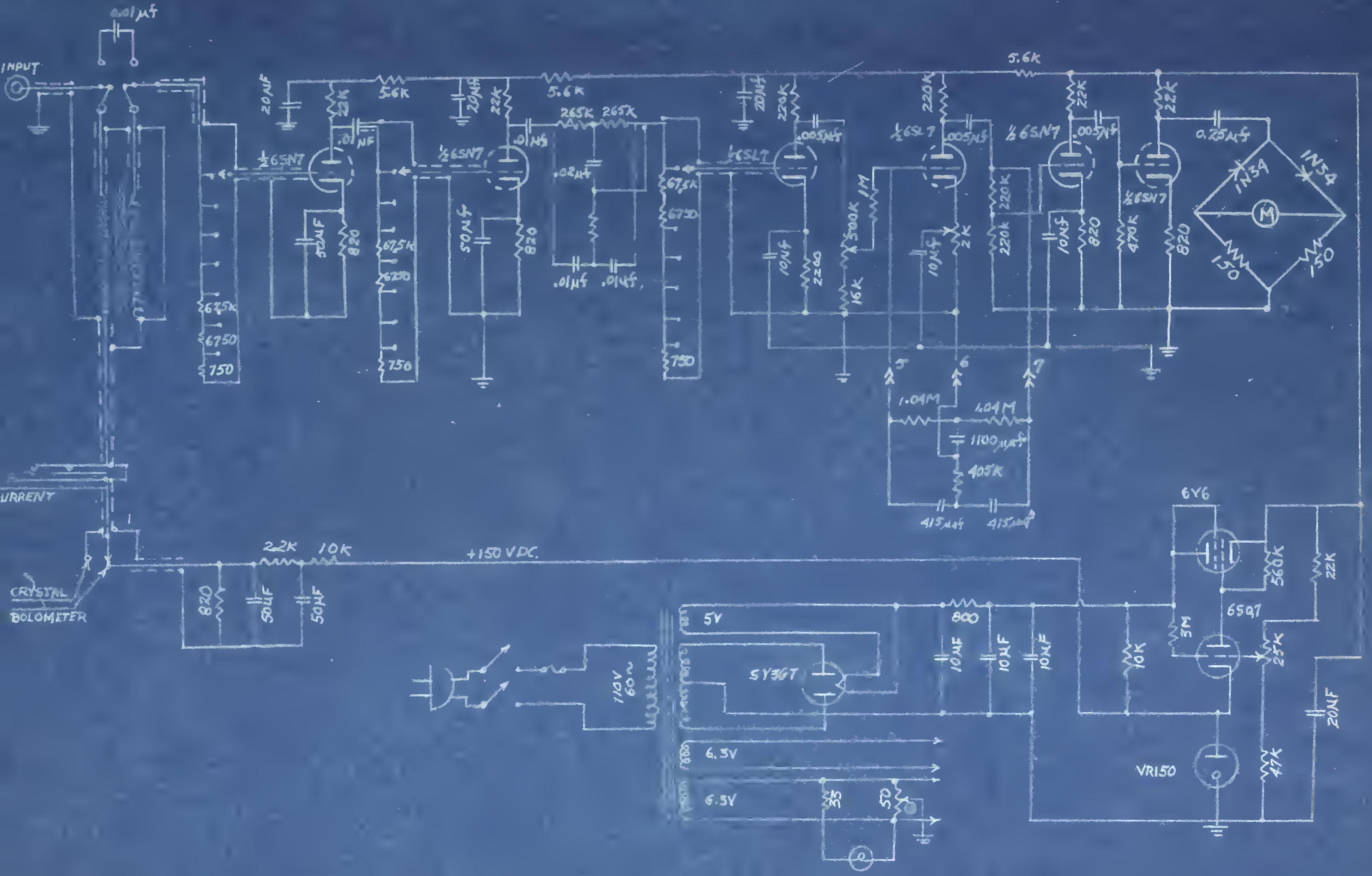

75K
.0005mf
150K
6AT
.1M
1mf
100K
6Z7
MOD. ON-OFF
OUTPUT LEAD
F.I.
2
1
SHELL
CATHOD.
723A
B-
+
5Y4
45V
-255
27
154
1K
5W
200
2W
VR105
10uf
400V
+
Fil - Black
Cathode - Blue
- Yellow, B+ - Red.

POWER SUPPLY and 400 CYCLE MODULATOR. 723A/B KLYSTRON.


0.01µf
INPUT
20µF
22K
5.6K
.01µF
½6SN7
30µF
820
675K
6750
750
20µF
22K
5.6K
.01µF
½6SN7
50µF
820
265K
265K
.02µf
.01µf
.01µf
675K
6750
750
20µf
220K
.005µf
½6SL7
10µf
2200
500K
1M
16K
220K
.005µf
½6SL7
10µf
2K
220K
220K
220K
.005µf
½6SN7
10µf
820
5.6K
22K
½6SN7
470K
820
0.25µf
1N34
1N34
M
150
150
5
6
7
1.04M
1.04M
1100µµf
405K
415µµf
415µµf
URRENT
CRYSTAL
BOLOMETER
820
50µF
50µF
2.2K
10K
+150 VDC.
5V
5Y3GT
110V
60~
6.5V
6.5V
35
50
800
10µF
10µF
10µF
10K
6Y6
560K
22K
6SQ7
3M
25K
20µF
47K
VR150

-hp- Model 415A Standing Wave Indicator.

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